EARTHQUAKE MITIGATION: REAUTHORIZING THE NATIONAL EARTHQUAKE HAZARDS REDUCTION PROGRAM

FIELD HEARING

BEFORE THE

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
HOUSE OF REPRESENTATIVES

ONE HUNDRED FIFTEENTH CONGRESS

SECOND SESSION

MAY 31, 2018

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EARTHQUAKE MITIGATION: REAUTHORIZING THE NATIONAL EARTHQUAKE HAZARDS REDUCTION PROGRAM

THURSDAY, MAY 31, 2018

HOUSE OF REPRESENTATIVES,
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY,
Washington, D.C.

The Committee met, pursuant to call, at 2:03 p.m., in the Huntington Beach Civic Center, 2000 Main Street, Huntington Beach, CA, Hon. Dana Rohrabacher presiding.

LAMAR S. SMITH, Texas
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Earthquake Mitigation: Reauthorizing the National Earthquake Hazards Reduction Program

Thursday, May 31, 2018
2:00 p.m. – 4:00 p.m.
Huntington Beach Civic Center, 2000 Main Street,
Huntington Beach, CA 92648

Witnesses

Dr. Steven McCabe, Director, National Earthquake Hazards Reduction Program; Group Leader, Earthquake Engineering Group, National Institute of Standards and Technology

Dr. Stephen Hickman, Director, USGS Earthquake Science Center, U.S. Geological Survey

Dr. Frank Vernon, Research Geophysicist, Institute of Geophysics and Planetary Physics, Scripps Institution of Oceanography, University of California San Diego

Mr. Chris D. Poland, Consulting Engineer; NIST Community Resilience Fellow

Mr. Ryan Arba, Branch Chief, Earthquake and Tsunami Program, California Governor's Office of Emergency Services

U.S. HOUSE OF REPRESENTATIVES
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

HEARING CHARTER

May 31, 2018

TO: Members, Committee on Science, Space, and Technology

FROM: Majority Staff, Committee on Science, Space, and Technology

SUBJECT: Field Committee Hearing: "Earthquake Mitigation: Reauthorizing the National Earthquake Hazards Reduction Program"

The Committee on Science, Space, and Technology will hold a hearing titled *Earthquake Mitigation: Reauthorizing the National Earthquake Hazards Reduction Program"* on Thursday, May 31, 2018 at 2:00 p.m. PT/5:00 p.m. ET at the Huntington Beach Civic Center, 2000 Main Street, Huntington Beach, CA 92648.

Hearing Purpose:

The purpose of the hearing is to review the federal National Earthquake Hazards Reduction Program (NEHRP), to examine the strengths, weaknesses, and challenges of the 40-year interagency effort, and to receive recommendations for future reauthorization of the program.

Witness List

- **Dr. Steven McCabe**, Director, National Earthquake Hazards Reduction Program; Group Leader, Earthquake Engineering Group, National Institute of Standards and Technology
- **Dr. Stephen Hickman**, Director, USGS Earthquake Science Center, U.S. Geological Survey
- **Dr. Frank Vernon**, Research Geophysicist, Institute of Geophysics and Planetary Physics, Scripps Institution of Oceanography, UC San Diego
- **Mr. Chris D. Poland**, Consulting Engineer; NIST Community Resilience Fellow
- **Mr. Ryan Arba**, Branch Chief, Earthquake and Tsunami Program, California Governor's Office of Emergency Services

Staff Contact

For questions related to the hearing, please contact Jenn Wickre of the Majority Staff at 202-225-6371.

Present: Representatives Rohrabacher, McNerney, and Takano.

Mr. ROHRABACHER. The Committee on Science, Space, and Technology will come to order.

Without objection, the Chair is authorized to declare a recess of the Committee at any time.

Good morning, and welcome to today's hearing entitled "Earthquake Mitigation: Reauthorizing the National Earthquake Hazards Reduction Program."

I recognize myself for five minutes for an opening statement.

Again, welcome to my colleagues to Huntington Beach. I am very pleased that you both came today. It is my honor, of course, to welcome you to Surf City, USA, but also the city that, I might add, is the city where we built the first stage of the Saturn rocket that took the first human beings to the moon. We are very proud of our beach culture. We are very proud of our aviation and our space achievements.

I am glad that two of my colleagues have been able to join us today, Representative Mark Takano and Jerry McNerney. Both have really been very active with me over the years, and actually we have very positive personal relationships with each other, and I think that demonstrates the type of cooperation that we want to see in Congress and that is exemplified by the Science Committee.

In California at any moment, we know that we could face a really big earthquake, not just a little shaker but a big earthquake. It is something that we can get complacent about because it always seems to be in the future that it might happen, and then when it doesn't we get complacent. Well, the risk is very real.

According to the USGS, California has a 99 percent chance of experiencing a magnitude 6.7 or larger earthquake over the next 30 years. The likelihood of an even larger earthquake, with a magnitude of 7.5 or greater, is 46 percent, and such an earthquake would likely occur in the southern part of California. So this is a major threat that we need to look at.

But California, of course, is not alone when it comes to this. Close to 75 million people in 39 states face some risk of an earthquake.

For 40 years the National Earthquake Hazards Reduction Program—now I am going to have to be reminded—how do we pronounce that? NEHRP. Okay, now I know how to say it. NEHRP has supported efforts to assess and monitor earthquake hazards and risks here in the United States.

Four Federal agencies coordinate their earthquake activities under NEHRP: The U.S. Geological Survey, the National Science Foundation, the Federal Emergency Management Agency, and the National Institute of Standards and Technology. These agencies assess U.S. earthquake hazards, deliver notifications of seismic events, develop measures to reduce earthquake hazards, and conduct research to help reduce the overall U.S. vulnerability to earthquakes.

Congress had last reviewed and reauthorized this program in 2004, and that law expired in 2009. Although Congress continues, however, to appropriate funds for this important work, we are long overdue in reauthorizing this program. We must ensure it is effective and up-to-date with the latest knowledge and science for monitoring and mitigation of earthquakes.

I am particularly interested in how we can improve the use of data to advance the deployment of an effective earthquake early warning system. I will be very interested in hearing if that is even possible, and to what degree we could use this as a goal. Such a system would automatically send an alert to areas in danger of potential shaking after the earthquake has been initially triggered. The alert would potentially allow components of the lifeline infrastructure such as electric utilities, railroad systems, and even hospital operating rooms, to cease activity that could be impaired by violent shaking before the first earthquake-triggered surface waves actually reach them.

We know that Senators Dianne Feinstein and Lisa Murkowski have introduced bipartisan legislation to reauthorize this agency and this operation. They have that in the Senate, and I will be working with my Science Committee colleagues to introduce a bill in the House very soon for this reauthorization.

I thank my witnesses for being here today, look forward to your expert testimony.

[The prepared statement of Mr. Rohrabacher follows:]

COMMITTEE ON
SCIENCE, SPACE, & TECHNOLOGY
Lamar Smith, Chairman

For Immediate Release
May 31, 2018

Media Contacts: Thea McDonald, Brandon VerVelde
(202) 225-6371

Statement by Rep. Dana Rohrabacher (R-Calif.)

Earthquake Mitigation: Reauthorizing the National Earthquake Hazards Reduction Program

Rep. Rohrabacher: Welcome to Huntington Beach. It's my honor to welcome you to California's 48th Congressional District and the world famous "Surf City."

I am glad that two of my colleagues on the Science Committee and fellow Californians, Rep. Mark Takano and Rep. Jerry McNerney, could join me in holding this hearing on a topic of great importance to our state and the nation.

In California, at any moment, we could face the next big earthquake. It's sometimes easy to get complacent, but the risk is real.

According to the U.S. Geological Survey (USGS), California has a 99 percent chance of experiencing a magnitude 6.7 or larger earthquake in the next 30 years. The likelihood of an even larger earthquake, magnitude 7.5 or greater, is 46 percent, and such an earthquake would likely occur in the southern part of the state.

But California is not alone. Close to 75 million people in 39 states face some risk from earthquakes.

For 40 years the National Earthquake Hazards Reduction Program (NEHRP) has supported efforts to assess and monitor earthquake hazards and risk in the United States.

Four federal agencies coordinate their earthquake activities under NEHRP: USGS, National Science Foundation (NSF), Federal Emergency Management Agency (FEMA) and National Institute of Standards and Technology (NIST).

These agencies assess U.S. earthquake hazards, deliver notifications of seismic events, develop measures to reduce earthquake hazards and conduct research to help reduce overall U.S. vulnerability to earthquakes.

Congress last reviewed and reauthorized the program in 2004, and that law expired in 2009. Although Congress continues to appropriate funds for this important work, we are overdue in reauthorizing the NEHRP law.

We must ensure it is effective and up-to-date with the latest knowledge and science for monitoring and mitigating earthquakes.

I am particularly interested in how we can improve the use of data to advance the deployment of an effective earthquake early warning system.

Such a system would automatically send an alert to areas in danger of potential shaking after the earthquake is initially triggered. The alert would potentially allow components of the lifeline infrastructure, such as electric utilities, railway systems and even hospital operating rooms, to cease activities that could be impaired by violent shaking before the first earthquake-triggered surface waves reach them.

Senators Dianne Feinstein (Calif.) and Lisa Murkowski (Alaska) have introduced a bipartisan NEHRP reauthorization bill in the Senate and I will be working with my Science Committee colleagues to introduce a bill in the House soon.

I thank the witnesses for being here today and I look forward to their expert testimony.

###

Mr. ROHRABACHER.Maybe we have an opening statement by Mr. Takano—I mispronounce your name after I have been talking to you for a decade now—Takano—there you go.

Mr. TAKANO. I want to welcome everyone to today's hearing. I just want to make sure that the live stream is functioning. I got some reports that it wasn't working on the Science Committee website yet.

I want to welcome everyone to today's hearing to review the nation's foremost earthquake research and risk mitigation activities under the National Earthquake Hazards Reduction Program, otherwise known as NEHRP. I look forward to our expert panel's assessment of the program's strengths, weaknesses, and challenges, and recommendations for improvements.

As an Inland Empire native, I am all too familiar with the damage that can be caused by earthquakes. Just this month, the Riverside area experienced a 4.5 earthquake followed by two smaller earthquakes. While there were no reports of injuries or damage, it reminds us that we need continued strong support of our Federal earthquake risk mitigation activities.

Now, I am proud to recognize in the audience Dr. David Oglesby—Dr. Oglesby is raising his hand in the back there, let the record show that—and Dr. Christos Kyriakopoulos—now I have a more difficult name than my name, Mr. Chairman—of the University of California, Riverside. They are both in the audience today, and they are from my district.

Set up on display way over at the back of the City Council Chambers is a 3D printed representation of the fault lines in the State of California that my university produced, and I have a smaller version of it. People think that the faults are maybe just one spine, but really you can see that it is a really amazing amalgamation of faults. To know that here is L.A., here is Huntington Beach, San Diego, and Riverside, you can see that we are sitting on top of numerous faults that come together.

Mr. Chairman, I want to let you know that the University has been so kind as to produce one of these for you and for Representative McNerney, and I hope that we can get one to each member of our delegation.

Mr. ROHRABACHER. We will keep it on the wall, unless it falls down in an earthquake.

[Laughter.]

Mr. TAKANO. But I think it will raise awareness of just how much we need to keep our eye on the ball.

We struggle with how to encourage cities and regions in high earthquake risk areas to implement mitigation measures, but I have a feeling that these kinds of demonstrations might help. We can't forget the importance of social and behavioral aspects of earthquake risk mitigation. I encourage everyone to take a look at the display, the big display, at the end of the hearing.

Following the devastating earthquakes in Alaska and California in 1964 and 1971, Congress established NEHRP and tasked four agencies—the National Science Foundation, the U.S. Geological Survey, the Federal Emergency Management Agency, otherwise known as FEMA, and the National Institute of Standards and Technology, otherwise known as NIST. NIST was tasked as the lead agency—to reduce the risks to life and property from future earthquakes. The good work of these agencies and their public- and private-sector partners has advanced the nation's understanding of earthquakes and provided the science that supports seismic design guidelines and standards for resilient buildings that save countless lives.

Unfortunately, economic damages are still very high after extreme natural hazards, and it is important to invest in community resilience. Resilient lifelines, such as roadways, pipelines, power lines, and communications infrastructure, can help get communities back up and running sooner after a big earthquake. In fact, the National Institute of Building Sciences recently released "National Hazard Mitigation Saves: 2017 Interim Report." It is a document, and it found that for every for $1 spent on hazard mitigation, the nation saves $6 in disaster costs.

Though the West Coast is widely known for its earthquake risk, the U.S. seismic hazard maps show that the central and eastern parts of the nation, as well as Puerto Rico and the U.S. Virgin Islands, are also categorized as having a high probability for strong earthquakes. Two hundred years ago, the New Madrid seismic zone in the middle of our country endured three 7.0 or higher earthquakes. Further, the composition of the earth under these regions allows the impact of an earthquake to be felt at several times the distance as an earthquake on the West Coast.

Now, while several countries in seismic prone areas have had earthquake early warning systems for many years, the U.S. continues to develop and implement pilot programs for a West Coast early alert system. I look forward to hearing from the panel today about what Congress can do to accelerate, and eventually expand, deployment of this lifesaving technology that can provide seconds to tens of seconds of time that could stop surgeries, keep airplanes in the air, and shut down nuclear power plants and other sensitive machinery. I also believe it is important that we better understand the current state of our infrastructure and buildings and how retrofitting can mitigate both the loss of life and the cost of rebuilding after an earthquake.

These issues are so very important to regions across the nation, and I thank the panel for their testimony before this Committee and as this Committee considers legislative priorities for NEHRP authorization.

Thank you, and I yield back, Mr. Chairman.

[The prepared statement of Mr. Takano follows:]

OPENING STATEMENT
Congressman Mark Takano (D-CA)

House Committee on Science, Space, and Technology
Field Hearing: *"Earthquake Mitigation: Reauthorizing the National Earthquake Hazards Reduction Program"*
May 31, 2018

I want to welcome everyone to today's hearing to review the nation's foremost earthquake research and risk mitigation activities under the National Earthquake Hazards Reduction Program. I look forward to our expert panel's assessment of the program's strengths, weaknesses, and challenges and recommendations for improvements.

As an Inland Empire native, I am all too familiar with the damage that can be caused by earthquakes. Just this month, the Riverside area experienced a magnitude 4.5 earthquake followed by two smaller earthquakes. While there were no reports of injuries or damage, it reminds us that we need continued strong support of our federal earthquake risk mitigation activities.

I am proud to recognize Dr. David Oglesby and Dr. Christos Kyriakopoulos of the University of California, Riverside in the audience today from my district. Set up on display at the back of the City Council Chambers is a 3D print of the fault lines in the state of California that UCR produced. We struggle with how to encourage cities and regions in high earthquake risk areas to implement mitigation measures, but I have a feeling these kinds of demonstrations might help. We can't forget the importance of social and behavioral aspects for earthquake risk mitigation. I encourage everyone to take a look at the display at the end of the hearing.

Following devastating earthquakes in Alaska and California in 1964 and 1971, Congress established NEHRP and tasked four agencies - the National Science Foundation, U.S. Geological Survey, the Federal Emergency Management Agency, and the National Institute of Standards and Technology, the lead agency - to reduce the risks to life and property from future earthquakes. The good work of these agencies and their public and private sector partners has advanced the nation's understanding of earthquakes and provided the science that supports seismic design guidelines and standards for resilient buildings that save countless lives.

Unfortunately, economic damages are still very high after extreme natural hazards occur, and it is important to invest in community resilience. Resilient lifelines, such as roadways, pipelines, power lines, and communications infrastructure, can help get communities back up and running sooner after a big earthquake. In fact, the National Institute of Building Sciences' recently released *National Hazard Mitigation Saves: 2017 Interim Report* found that every for $1 dollar spent on hazard mitigation the nation saves $6 in disaster costs.

Though the west coast is widely known for its earthquake risk, the U.S. seismic hazard maps show that the central and eastern parts of the nation, as well as Puerto Rico and the U.S. Virgin Islands, are also categorized as having a high probability for strong earthquakes. Two hundred years ago, the New Madrid seismic zone in the middle of the country endured three magnitude 7.0 or higher earthquakes. Further, the composition of the earth under these regions allows the impact of an earthquake to be felt at several times the distance as an earthquake on the West Coast.

While several countries in seismic prone areas have had earthquake early warning systems for many years, the U.S. continues to develop and implement pilot programs for a west coast early alert system. I look forward to hearing from the panel about what Congress can do to accelerate, and eventually expand, deployment of this lifesaving technology that can provide seconds to tens of seconds of time to stop surgeries, keep airplanes in the air, and shut down nuclear power plants and other sensitive machinery. I believe it's also important that we better understand the current state of our infrastructure and buildings and how retrofitting can mitigate both the loss of life and the cost of rebuilding after an earthquake.

These issues are so very important to regions across the nation, and I thank the panel for their testimony as this Committee considers legislative priorities for NEHRP authorization.

Thank you and I yield back.

Mr. ROHRABACHER. Thank you, Congressman Takano.

And now, Congressman McNerney.

Mr. MCNERNEY. Well, I thank the Chairman, my friend from Huntington Beach, for calling this hearing. I thank the panelists for coming in, and I am looking forward to your testimony.

My district is a little north of here. It is in the Delta region of California. So we have the confluence of the San Joaquin River and the Sacramento River forming the California Delta. It has an extensive system of levies. Many are very aged, so we are very concerned.

The Governor has a plan to put in tunnels, and we need to understand what the seismic risks of that project may be.

But in all, we see damage when we have earthquakes, and it is so important to have a set of very good standards that mitigate or help us mitigate the damage. For example, we have seen in other countries in the last century earthquakes of a magnitude of 4 to 5 that have caused immense damage and thousands upon thousands of deaths, whereas in this country we have earthquakes on the order of a magnitude of 7 on the Richter scale, and we have seen tragic damage, but nothing on the scale that we have seen overseas.

So these standards are very, very important to the health and safety and economic well-being of our communities and our country. That is why NEHRP's mission is so important, and we want to make sure that we understand what sort of objectives are realistic with your mission, with NEHRP's mission, and how we can obtain those objectives, how much it is going to cost, and so on.

So I welcome your testimony, and I look forward to the back and forth afterwards.

Thank you, Mr. Chairman.

[The prepared statement of Ranking Member Eddie Bernice Johnson:]

OPENING STATEMENT

Ranking Member Eddie Bernice Johnson (D-TX)

House Committee on Science, Space, and Technology
Field Hearing: *"Earthquake Mitigation: Reauthorizing the National Earthquake Hazards Reduction Program"*
May 31, 2018

I welcome today's hearing on reauthorization of the National Earthquake Hazards Reduction Program.

Congress last authorized the programs and activities carried out under NERHP in 2004. The Committee has only held two oversight hearings on this important program since the previous authorization expired in 2009. The Science Committee should be leading the efforts to review this 40-year-old program's past successes and challenges and to make determinations for how it will administered in the future. As I have said before, I am disappointed that this Committee neglects its responsibilities as an authorizing committee to examine and make funding recommendations for important science agency programs. I am glad we are exploring the state of earthquake hazards risk reduction efforts today, and I look forward to the witnesses' recommendations for improvements to NEHRP as this Committee, hopefully, moves forward with reauthorization of this critical program.

It has been more than 50 years since the devastating magnitude 9.2 Alaska earthquake and resulting tsunamis took 139 lives and caused $2.3 billion in damage, in today's dollars. And almost 25 years have passed since a fatal magnitude 6.7 earthquake struck the Northridge neighborhood of Los Angeles claiming 57 lives, many thousands of injuries, and $20 billion in damage. As a nation we cannot let time make us complacent in our earthquake preparedness. Congress has continued to fund NEHRP and the four agencies tasked with carrying out earthquake hazard risk mitigation at an average of about $125 million per year.

The National Science Foundation and the U.S. Geological Survey carry out fundamental research in the earth sciences. Both agencies have extensive networks of instrumentation that record seismic activity, providing information that advances our understanding of the occurrence and intensity of earthquakes. While the National Institute of Standards and Technology is the lead agency for NEHRP, NIST also carries out applied research that provides the scientific basis for earthquake resilient building codes and design guidelines. And FEMA helps develop and promote the implementation of these building codes and standards, seismic mitigation plans, and earthquake training and awareness for States and territories.

We may not be able to tell when or where the next earthquake will strike, but because of NEHRP we are better prepared to mitigate the risk than we were 40 years ago. However, we still have much more work to do when it comes to earthquake early warning and community resilience. I thank the witnesses for being here to offer their expertise on improvements to NEHRP as this Committee considers authorization.

Thank you and I yield back.

Mr. ROHRABACHER. Thank you, Congressman McNerney.

This is a very serious issue today. This is very serious because we know that this potential dangerous situation is hanging right there. It could happen tomorrow, and it could happen ten years from now or 100 years from now, but we know it could happen tomorrow. We need to make sure we are prepared, and I appreciate my two colleagues joining us today, and I appreciate the witnesses that we have.

We have first-class witnesses to help us understand the threat and how we should move forward, if there are ways to move forward, to mitigate this challenge.

I will introduce the witnesses, and we will start.

The first witness today is Dr. Steven McCabe, Director of the National Earthquake Hazards Reduction Program. Let me note that the leader of the Earthquake Engineering Group is also there with NIST. Dr. McCabe has received both his Bachelor of Science and Master of Science inmechanical engineering from Colorado State University. He also earned a Ph.D. in civil engineering from the University of Illinois at Urbana-Champaign.

Dr. Stephen Hickman, our second witness today, is Director of the U.S. Geological Survey Earthquake Science Center in Menlo Park. Dr. Hickman received a bachelor degree in geology from Earlham College, as well as a Ph.D. in solid Earth geophysics from MIT.

And then Dr. Frank Vernon, our third witness today. He is a Research Geophysicist at the Institute of Geophysics and Planetary Physics at the Scripps Institute of Oceanography at the University of California at San Diego. Boy, that is a mouthful.

[Laughter.]

Mr. ROHRABACHER. He is also the Director for the USArray Network Facility for the NSF EarthScope Program. Dr. Vernon received a B.A. in physics from UC–San Diego, and a Ph.D. in Earth science from Scripps Institute of Oceanography.

We also have with us Chris Poland, our fourth witness. He is a consulting engineering and a NIST Community Resilience Fellow. He previously served as Chairman of NEHRP on the NEHRP Advisory Committee. Mr. Poland earned his Bachelor of Science in mathematics from the University of Redlands and his Master in Science in structural engineering from Stanford University.

Our final witness today is Mr. Ryan Arba, a Branch Chief of the Earthquake and Tsunami Program in the California Governor's Office of Emergency Services. He oversees the state's preparedness efforts for seismic events. Mr. Arba received a degree in social and behavioral sciences from Cal State Monterey Bay, and a master's in public administration from the University of Southern California.

I would suggest that if we keep it down to five minutes apiece, we then will have a dialogue, which is what this hearing was intended for.

So I now recognize Dr. McCabe for five minutes to present his testimony.

TESTIMONY OF DR. STEVEN MCCABE, DIRECTOR, NATIONAL EARTHQUAKE HAZARDS REDUCTION PROGRAM; GROUP LEADER, EARTHQUAKE ENGINEERING GROUP, NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY

Dr. MCCABE. Thank you. Chairman Rohrabacher, Congressman Takano, Congressman McNerney, I am Dr. Steven McCabe, the Director of the National Earthquake Hazards Reduction Program, or NEHRP. Thank you for the opportunity to appear before you today to discuss NIST's role in reducing the earthquake risk facing U.S. communities. NIST is the lead agency in the four-agency partnership that is NEHRP. The Federal Emergency Management Agency, the National Science Foundation, and the U.S. Geological Survey are the other three partners.

Earthquake concerns are truly national in scope. Forty-two states and a number of territories face serious risk from earthquakes. The 1971 San Fernando earthquake caused serious damage and was a motivating factor for the creation of NEHRP. More recently, there have been significant increases in seismic activity in southern Kansas and in Oklahoma. There are simply no areas of the nation with zero risk from earthquakes.

Mitigation efforts through such efforts as improved building codes can make a significant difference in saving lives, which is the primary goal of earthquake-related provisions in U.S. building codes and standards, the NEHRP agency's work to perform needed research and to translate research results into actions that mitigate the impact on the nation. These include the development of national hazard models and maps; disaster investigations concerning engineering, geology, seismology, and social science aspects of an earthquake; participation in the development of model building codes and associated standards; and the funding of basic research.

NIST carries out applied research to develop and deploy advances in measurement science related to earthquake engineering, including standards to enhance disaster resilience of buildings, infrastructure, and communities. NIST research has provided data to support improved codes and standards through testing of structural elements, developed improved modeling and assessment techniques for existing buildings, and assess the impact of new materials in improving seismic performance. NIST is actively collaborating with FEMA in addressing non-ductile concrete building performance such as that noted in the Los Angeles area concerning older buildings. NSF funded initial work on this problem. In 2015, the City of Los Angeles enacted ordinance 183893, which is a mandatory retrofit program for soft first-story wood-frame buildings and non-ductile concrete buildings. Seismologist Dr. Lucy Jones, on loan from USGS and working with the City of Los Angeles, was a key voice in this process. Thus, the enactment of this important ordinance is a result of the activity of all four NEHRP agencies in addressing this problem.

Preventing collapse so that occupants could safely leave damaged buildings has been the goal inherent in building codes since their inception in 1915. However, there has been a growing call for expedited recovery from earthquake and other natural hazard events.

Significant economic interruptions due to earthquake damage are no longer acceptable.

NIST has initiated a large effort to aggressively study the engineering, social, economic, and policy issues concerning making communities resilient. A community resilience planning guide has been developed for us by local communities in planning their own resilient future. NIST also has funded a resilience center to provide tools for communities as they forge a resilient future.

Improved building performance is another aspect of moving towards resilience. A recent study completed by NIST considered what would be required in terms of research and implementation for adoption of an immediate occupancy performance objective for building design. The concept is to improve building performance to the point that occupants would be able to quickly reoccupy business and residential buildings following a natural hazard event.

NIST has worked with and looks forward to continuing to work with the House Committee on Science, Space, and Technology concerning reauthorization of NEHRP. Our challenge is to ensure that new knowledge and experience gained through NEHRP continues to be developed and applied to domestic practices and policies that foster a more resilient nation. We must keep working to mitigate the impacts of earthquakes on our communities. NEHRP is an integral part of the private-public collaboration that continues to reduce risk of damage to our communities from seismic ground motions.

Thank you again for the opportunity to testify on NEHRP, and I am happy to answer any questions that you may have.

[The prepared statement of Dr. McCabe follows:]

Testimony of

Steven L. McCabe Ph.D., P.E.

Director
National Earthquake Hazards Reduction Program
Engineering Laboratory
National Institute of Standards and Technology
U.S. Department of Commerce

Before the

Committee on Science, Space, and Technology
U.S. House of Representatives
Field Hearing
Huntington Beach, California

A Review of the National Earthquake Hazards Reduction Program (NEHRP)

May 31, 2018

Introduction

Chairman Smith, Ranking Member Johnson, and Members of the Committee, my name is Dr. Steven McCabe, and I am the Director of the National Earthquake Hazards Reduction Program (NEHRP or Program), located within the Engineering Laboratory at the National Institute of Standards and Technology (NIST) in the Department of Commerce. NIST leads the four-agency NEHRP partnership, which includes the Federal Emergency Management Agency (FEMA), the National Science Foundation (NSF), and the U.S. Geological Survey (USGS). Thank you for the opportunity to appear before you today to discuss NIST's and NEHRP's role in making measurable progress towards reducing the earthquake risk facing U.S. communities.

Earthquake concerns are truly national in scope. Forty-two states and a number of territories face serious risk from earthquakes. In recent decades, the United States has experienced a relatively quiet period of major seismic activity. We have not experienced the likes of the damage caused by the 1964 Alaska earthquake, the 1971 San Fernando earthquake (a motivating factor for the creation of NEHRP), the 1989 Loma Prieta earthquake, or the 1994 Northridge earthquake. More recently, the United States has experienced significant increases in seismic activity in areas of the country not generally associated with earthquakes, including in southern Kansas and in Oklahoma, and the 2011 Mineral, Virginia, earthquake was a wakeup call for the eastern portion of the United States.[1] There are simply no areas of the Nation with zero risk from earthquakes. Furthermore, since the last major U.S. earthquakes occurred, the Nation has continued to concentrate more of its populations into urban areas, exposing higher percentages of people and structures to devastation from a single large earthquake or resulting tsunami.

Mitigation efforts, through such measures as improved building codes, can make a significant difference in saving lives, which is the primary goal of earthquake-related provisions in U.S. building codes and standards. The 2010 Haiti and Chile (Maule) earthquakes illustrated the need for and effectiveness of modern building codes and sound construction practices. In Haiti, where building codes are minimal at best, the M7.0 earthquake resulted in a death toll estimated at over 220,000. By contrast, Chile has more modern building codes, based on U.S. model building codes and standards, and the M8.8 Maule earthquake resulted in approximately 500 deaths.[2] NEHRP was created to address the reality that earthquakes are inevitable and will occur without warning, but that there is much the Nation can do to reduce their consequences.

NEHRP Organization and Background

Congress created NEHRP through the Earthquake Hazards Reduction Act of 1977 (Public Law 95-124) and the Program was last reauthorized under the National Earthquake Hazards Reduction Program Reauthorization Act of 2004 (Public Law 108-360). The NEHRP Reauthorization Act designated NIST as the NEHRP Lead Agency with primary responsibility for planning and coordinating the Program. Pending passage of new reauthorizing legislation, the NEHRP agencies continue to perform duties outlined in Public Law 108–360 within agency-established budget allocations.

[1] https://news.nationalgeographic.com/news/2014/07/140717-usgs-earthquake-maps-disaster-risk-science/.

[2] https://www.earthmagazine.org/article/chiles-quake-larger-less-destructive-haitis

The 2004 Reauthorization Act also created the Advisory Committee on Earthquake Hazards Reduction and the NEHRP Interagency Coordinating Committee, each providing important input to the Program.

The Advisory Committee on Earthquake Hazards Reduction (ACEHR) is a Federal Advisory Committee that assesses effectiveness of the program. The ACEHR consists of 15 leading earthquake professionals from across the U.S. and provides advice to the NEHRP agencies on issues concerning earthquake hazard assessment and risk mitigation.

The Interagency Coordinating Committee (ICC) is comprised of the principals of the four NEHRP agencies, plus the Director of the Office of Management and Budget and the Director of the Office of Science and Technology Policy. One major action of the ICC was to approve the NEHRP Strategic Plan.

NEHRP Strategic Plan

The Strategic Plan, required under the National Earthquake Hazards Reduction Program Reauthorization Act of 2004, presented NEHRP's vision for our Nation: *A Nation that is earthquake-resilient in public safety, economic strength, and national security.*

This vision recognizes the importance of not only improving public safety in future earthquakes but also enhancing national economic strength and security, and highlights the need for improving national resilience following future damaging earthquakes.

The Strategic Plan set three overarching program goals that involve synergies among the agencies: (A) improve understanding of earthquake processes and impacts (basic research); (B) develop cost-effective measures to reduce earthquake impacts on individuals, the built environment, and society-at-large (applied research and development); and, (C) improve the earthquake resilience of communities nationwide.

The Plan also outlines nine areas of *strategic priority* for the Program:

(1) fully implement the Advanced National Seismic System (ANSS);
(2) improve techniques for evaluating and rehabilitating existing buildings;
(3) further develop Performance-Based Seismic Design (PBSD);
(4) increase consideration of socioeconomic issues related to hazard mitigation implementation;
(5) develop a national post-earthquake information management system;
(6) develop advanced earthquake risk mitigation technologies and practices;
(7) develop guidelines for earthquake-resilient lifeline components and systems;
(8) develop and conduct earthquake scenarios for effective earthquake risk reduction and response and recovery planning; and,
(9) facilitate improved earthquake mitigation at state and local levels.

I am very pleased to report significant progress in the goals and areas of strategic priority in the Plan, notably the improvements in national seismic instrumentation, improvements in building codes and in the application of PBSD, and continued work at the state and local levels to implement mitigation efforts. However, much remains to be done especially concerning the existing building stock, the risk mitigation of lifelines such as those supplying electricity, water and wastewater and communication services and in improving the resilience of communities to seismic events.

To continue looking to the future, ongoing work with scenarios is helping to guide future direction of the Program. USGS just released a scenario, the HayWired Scenario, on April 18, 2018, the anniversary of the 1906 San Francisco earthquake. The HayWired Scenario depicts a realistic scenario based on a M7.0 earthquake on the Hayward fault system in the San Francisco Bay Area, the estimated impacts on infrastructure, communities and individuals can be seen as significant. These USGS scenarios continue to offer NEHRP a means to evaluate current and future Program activities to meet the issues identified by these scenarios. [3]

NEHRP Agencies

The NEHRP agencies work to perform needed research and translate the research results into actions that mitigate the impact on the Nation. The NEHRP agencies work in partnership, with each agency fulfilling its unique role in the Program. NEHRP performs inherently governmental roles including: the development of national hazard models and maps; disaster investigations concerning engineering, geology, seismology and social science aspects of an earthquake; participation in the development of model building codes and associated standards; and the funding of basic research.

The Program extends beyond the four NEHRP agencies to include other Federal agencies, state and local governments, non-governmental professional organizations, model building code and standards organizations, and earthquake professionals in the private sector and academia. Without this extended community of dedicated earthquake professionals, the NEHRP agencies could not fulfill their statutory responsibilities nearly as well.

USGS

The USGS, also testifying here today, is the applied earth science component of NEHRP. USGS delivers rapid characterization of earthquake size, location, and impacts; develops seismic hazard assessment maps and related mapping products; builds public awareness of earthquake hazards; and supports targeted research to improve monitoring and assessment capabilities.

NSF

NSF is NEHRP's primary basic research arm, supporting research that addresses earth science, geotechnical and structural engineering, lifeline engineering, and the social sciences and supports the education of future generations of earthquake practitioners across the Nation.

FEMA

FEMA has the NEHRP leadership role in working with the practitioner community, the American Society of Civil Engineers, and the International Code Council to support the

[3] https://www.usgs.gov/natural-hazards/science-application-risk-reduction/science/haywired-scenario?qt-science_center_objects=0#qt-science_center_objects
http://usgs.maps.arcgis.com/apps/webappviewer/index.html?id=14d2f75c7c4f4619936dac0d14e1e468

development of model building codes and standards provisions that form the basis for most state and local building codes in the U.S.

NIST

NIST has a dual role within NEHRP. NIST leads the Program with responsibilities that include Chairing the ICC and establishing the ACEHR; drafting and updating NEHRP strategic and management plans; submitting annual reports to Congress on NEHRP activities; and fostering interagency coordination and cooperation.

NIST also carries out applied research to develop and deploy advances in measurement science related to earthquake engineering, including performance-based tools, guidelines, and standards for designing buildings to resist earthquake effects and to improve building safety, and to enhance disaster resilience of buildings, infrastructure, and communities. NIST has devoted considerable effort in supporting the further development of PBSD concepts, conducting a seminal comparison of design outcomes from PBSD and traditional building code design approaches.[4] NIST's research has also (1) provided data to support improved codes and standards for use by structural engineers through testing of structural elements under seismic loading; (2) developed improved modeling and assessment techniques for existing buildings; and (3) assessed the impact of new materials in improving seismic performance.[5] NIST is also examining historical costs of strengthening Federal buildings for improved seismic performance to gain insight into the costs associated with future mitigation options. [6]

NEHRP Agencies Collaboration

NIST is actively collaborating with FEMA in addressing nonductile concrete building performance, such as that noted in the Los Angeles area for older buildings designed prior to the 1980's when building codes did not provide the performance levels of codes now in effect. Research over the past 30 years, much of it funded by the NEHRP agencies, has provided information for engineers concerning the design of reinforced concrete buildings to withstand even higher levels of shaking than was the basis in these older codes. Current work by NIST is developing new modeling approaches for more accurately predicting capacity of these older concrete structures. These older buildings can be identified for additional study using triage tools developed by FEMA. It is important to note that NSF funded initial work on this problem that led to significant attention by the public and by local governments.

Another class of building that has been found to perform poorly in strong earthquakes is soft first story wood buildings, defined as multi-story buildings with openings in the first story typically for parking. The openings reduce the lateral capacity of the first floor, which can cause collapse during strong shaking, as was seen in the Northridge earthquake of 1994. FEMA has published a number of studies in retrofit approaches for these buildings for use by engineers. Moreover, NSF funded research into the performance of these types of structures, including full scale shake table testing. The result is that in 2013, San Francisco enacted the Mandatory Soft Story Retrofit Program, based in part on work sponsored by NEHRP, and on the observed effects during the 1989 Loma Prieta earthquake where many building failures of this type were noted.

[4] https://nvlpubs.nist.gov/nistpubs/TechnicalNotes/NIST.TN.1863-1.pdf.
[5] https://nehrp.gov/.
[6] https://dx.doi.org/10.6028/NIST.TN.1973.

In 2015, the City of Los Angeles enacted Ordinance 183893, which is a mandatory retrofit program for these two classes of buildings, soft first story wood-frame buildings and the nonductile concrete buildings. Seismologist Dr. Lucy Jones, on loan from USGS and working with the City of Los Angeles, was a key voice in this process. Thus, the enactment of this important ordinance is a direct result of the activity of all four NEHRP agencies in addressing this problem.[7]

NEHRP agencies continue to work with other Federal agencies to increase seismic risk awareness and resiliency for the Federal community. For example, NIST NEHRP worked closely with Federal agencies on their implementation progress reports. The first round of reports was received in early April 2018 and provides information on new building design activity and significant insight into the existing Federal building inventory. The reporting process also provides the opportunity for dialogue with agencies on best practices, research developments and sharing of other information across agencies regarding this important subject. Along these same lines, in September of 2016, the U.S. Government Accountability Office issued "Earthquakes: Additional Actions Needed to Identify and Mitigate Risks to Federal Buildings and Implement an Early Warning System," that focused on seismic safety of existing federally owned and leased buildings. This information complements the data obtained from the recent progress reports.[8]

NEHRP – Beyond Life Safety

The design of structures in the U.S. historically has focused on life safety. Preventing collapse so that occupants could safely leave damaged buildings has been the goal inherent in building codes since their inception in 1915. However, starting with Loma Prieta in 1989 and Northridge 1994, there has been a growing call for expedited recovery from earthquake and other natural hazard events. Significant economic interruptions due to earthquake damage are no longer acceptable. The impact of earthquake damage can be dramatically shown by recent earthquakes. One example includes the 1995 M6.9 earthquake that struck Kobe, Japan, severely damaging its major port facilities. What was once the world's sixth busiest container port immediately dropped to 25th in the world and has not regained its pre-earthquake status nearly 23 years later.

While life safety is essential to achieve in design, there also must be recognition of the need for resilience to natural hazard events and for improved building performance to reduce damage. NIST has initiated a large effort to aggressively study the engineering, social, economic, and policy issues concerning making communities resilient. NIST developed the *Community Resilience Planning Guide* for use by local communities in planning their own resilient future.[9] This effort connects to the SPUR, the San Francisco Bay Area Planning and Urban Research Association, efforts in California[10] and to the Rockefeller 100 Resilient Cities program.[11] NIST

[7] http://www.ladbs.org/services/core-services/plan-check-permit/plan-check-permit-special-assistance/mandatory-retrofit-programs.
[8] https://www.gao.gov/products/GAO-16-680.
[9] https://www.nist.gov/topics/community-resilience/community-resilience-planning-guide.
[10] https://www.spur.org/
[11] https://www.100resilientcities.org/.

also has funded a resilience center to provide tools for communities as they forge a resilient future.[12]

NIST provides communities with an economic decision framework for the evaluation of investment strategies designed to improve community resilience. NIST participated in the development of a new standard that was issued by ASTM International in April 2018. ASTM E3130 "Standard Guide for Developing Cost-Effective Community Resilience Strategies."[13]

Improved building performance is another aspect of moving towards resilience. A recent study completed by NIST and Resilient Community Groups considered what would be required in terms of research and implementation for adoption of an "Immediate Occupancy" performance objective for building design. The goal is to improve building performance to the point that occupants would be able to quickly re-occupy business and residential buildings following a natural hazard event. A change to an immediate occupancy design philosophy represents a significant step beyond the traditional goal of life safety in building design. Properly achieved, the serious economic impact noted in the examples cited above could be avoided or reduced. However, a change to immediate occupancy design is a sweeping concept requiring more deliberate study into its engineering, economic, social, and policy aspects.

As we conclude 40 successful years of NEHRP, we are entering a new era of possibilities. The demand for improved building performance and reduced economic and social impacts from disasters of all kinds, offers a real opportunity for NEHRP not only to continue its successful, collaborative partnership but to incorporate changes in knowledge and technology together with social expectations to examine how to reduce the risk of damage from earthquake to a greater degree than has historically been the case. The country needs resilient communities and reduced losses from natural hazards. While we don't know when major earthquakes will occur in the future, we do know that with continued effort by the NEHRP agencies, engagement with both communities and earthquake professionals we can improve the performance of our Nation when future earthquakes occur.

NEHRP Reauthorization

NIST has worked with and looks forward to continuing to work with the House Committee on Science, Space and Technology concerning reauthorization of NEHRP.

In the decade since the passage of the public law, new needs have been identified—new seismic activity has been identified, new programs are in place at agencies and, importantly, new knowledge is available for use in the mitigation effort. Reducing the damaging impacts of earthquakes is a national problem. Earthquakes cross state boundaries, and state-federal partnerships are therefore critical. Solutions to earthquake-related problems can best be handled in a coordinated manner that crosses jurisdictional boundaries. In addition, the engineering industry that addresses almost all earthquake mitigation problems is composed of many small

[12] http://resilience.colostate.edu/.
[13] https://www.astm.org/newsroom/new-astm-international-standard-supports-community-resilience

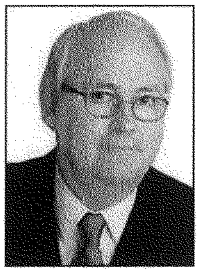
entities, so that private sector efforts alone are simply inadequate to address major challenges. Federal leadership continues to be critical to this endeavor.

Conclusion

Our challenge is to ensure that the new knowledge and experience gained through NEHRP continues to be developed and applied to domestic practices and policies that foster a more resilient Nation. We must keep working to mitigate the impacts of earthquakes on our communities. Painful lessons from past earthquakes must not be repeated. NEHRP is an integral part of the private-public collaboration that continues to reduce risk of damage to our communities from seismic ground motions.

Thank you again for the opportunity to testify on NEHRP. I am happy to answer any questions that you may have.

Steven L. McCabe



Steven McCabe is the NEHRP Director, providing overall program management and coordination; facilitating implementation of earthquake risk mitigation measures; and building and maintaining effective partnerships with stakeholders in industry, academia and government and the four NEHRP agencies. McCabe also is the Group Leader of the NIST Earthquake Engineering Group. In this position, he serves as the NIST representative on the NEHRP Program Coordination Working Group. He manages earthquake engineering research that is conducted in house at NIST or through outside contractors. The overall approach is to combine in-house and extramural expertise to address key research and knowledge-transfer issues in earthquake engineering.

Prior to joining NIST in 2011, McCabe worked in the private sector, in academia and at the Federal level. He was Chief Executive Officer of NEES Consortium, Inc. from 2007 to 2010, where he was responsible for management and operation of the George E. Brown, Jr., Network for Earthquake Engineering Simulation (NEES), funded by the National Science Foundation (NSF).

From 1985 to 2007, McCabe taught structural engineering courses and conducted research as a faculty member in the Department of Civil, Environmental, and Architectural Engineering at the University of Kansas, where he is a professor emeritus. He served as department chair from July 1998 through September 2002. His research interests included earthquake engineering and structural dynamics as well as the application of computer-based nonlinear analysis techniques to static and dynamic analysis problems. A particular interest is the identification of damage levels and reserve capacity in structures under dynamic loads.

During 2002–2005 McCabe served as program manager for the Structural Systems and Hazard Mitigation of Structures Program in the Division of Civil and Mechanical Systems at NSF. He managed research funding for structural performance under extreme loading, both natural and manmade, as well as supporting work in structural health monitoring.

Before beginning his academic career, McCabe worked in the private sector as a design and resident engineer primarily in the nuclear- and fossil-power industries. He is a registered professional engineer and has been active in many national and international professional societies.

Education:
Ph.D. Civil Engineering, 1987, University of Illinois at Urbana-Champaign
M.S. Mechanical Engineering/Engineering Mechanics, 1974, Colorado State University
B.S. Mechanical Engineering, 1972, Colorado State University
Fulbright Scholar, 1995–1996, Norwegian Institute of Technology in Trondheim

Mr. ROHRABACHER. Thank you very much for your testimony.
Dr. Hickman, you have five minutes.

TESTIMONY OF DR. STEPHEN HICKMAN, DIRECTOR, USGS EARTHQUAKE SCIENCE CENTER, U.S. GEOLOGICAL SURVEY

Dr. HICKMAN. Thank you, Congressman Rohrabacher and colleagues, for inviting the U.S. Geological Survey to this hearing. I am Steve Hickman, Director of the Earthquake Science Center. Our center has been a flagship USGS research center in the west for over 50 years. Here in Southern California, we have had an office in Pasadena for over 40 years, working closely with partners in Cal Tech and elsewhere.

The USGS is a committed partner in NEHRP. The agencies have continued to work closely together since the appropriations authority for NEHRP expired in 2009. NEHRP was founded on the belief that while earthquakes are inevitable, there is much that we can do as a nation to improve safety, reduce losses and impacts, and increase our resilience.

Within NEHRP, each agency performs a distinct and complementary role. The heart of this partnership is a shared commitment to translate the results of research and monitoring into actions that can reduce earthquake losses. The USGS role within NEHRP is to deliver the scientific data and information tools that engineers, emergency managers, government officials, and the public need to prevent earthquake hazards from becoming disasters.

USGS activities under NEHRP are implemented through the Earthquake Hazards Program and the Global Seismographic Network. We provide rapid, authoritative information on the magnitude, location, shaking intensity, and potential impacts of earthquakes both in the U.S. and around the world. The USGS also develops national and regional hazard assessment maps and detailed scenarios forecasting the impacts of anticipated major earthquakes, and we carry out targeted research to improve these products.

The USGS National Earthquake Information Center, which supports this work, is a 24/7 operation providing situational awareness for emergency responders and the public. This information is made possible by the earthquake monitoring networks that make up the Advanced National Seismic System, including regional seismic networks that the USGS supports through its academic partners.

Significant improvements to the ANSS were made in 2010 and 2011. In Fiscal Year 2018, we are continuing this effort by directing $5 million for deferred maintenance and, according to Congressional direction, $23 billion for build-out of the Earthquake Early Warning System called ShakeAlert. Congress has appropriated funds in recent years to continue development of this system, and the USGS is committed to working with Congress to determine the appropriate cost share for future ShakeAlert developments. Our goal is not simply to duplicate the early warning systems of other countries but to build the most advanced earthquake warning system in the world.

USGS research is supplemented by external research through grants and cooperative agreements. The Southern California Earthquake Center at University of Southern California, supported by the USGS and NSF, is an example of such a research partnership. We have supported research projects in various academic institutions across Southern California, including Cal Tech, USC, UCLA, UC–Irvine, and UC–San Diego. In 2017, our external research funding in the region amounted to $4.5 million.

All the best science, however, cannot guarantee that people are able to use the information to make informed decisions. Therefore, the USGS has supported publication of "Putting Down Roots in Earthquake Country," now available in eight different regions and in five languages. These and other USGS publications explain how residents can prepare for, survive, and recover from earthquakes.

We have learned much about earthquakes in California, and translated that knowledge into better building codes and better emergency response plans. While many critical pieces of infrastructure have been retrofitted to better withstand earthquake shaking, other infrastructure has lagged. Many seaports and some airports are built on land that is susceptible to liquefaction where shaking causes the soil to temporarily lose strength and cohesion and flow laterally, behaving something like quicksand.

Lastly, I want to remind the Committee of the annual great ShakeOut, which began in 2008 as part of a scenario of a great earthquake on the southern San Andreas Fault. This year's ShakeOut event happens in October on the 18th at 10:00 a.m. in the morning. People around the country and the world will participate in drills to practice safe responses to an earthquake. Please encourage enlisting your offices in participating at Shakeout.org.

In summary, the Department of the Interior supports reauthorization of NEHRP because it has been a successful interagency partnership that continues to make valuable contributions to the nation's resilience to earthquakes and other hazards.

On behalf of the USGS, thank you for this opportunity to testify today.

[The prepared statement of Dr. Hickman follows:]

Statement of

Steve Hickman

Director of the Earthquake Science Center

U.S. Geological Survey

before the

House Committee on Science, Space, and Technology

May 31, 2018

Thank you, Congressman Rohrabacher and colleagues, for inviting the U.S. Geological Survey (USGS) to participate in this hearing to discuss the National Earthquake Hazards Reduction Program. I am Steve Hickman, Director of the Earthquake Science Center. Our center has been a flagship USGS research center in the West for over 50 years. We have offices in Menlo Park, Pasadena, Seattle, Anchorage, and Albuquerque. The USGS also hosts the National Earthquake Information Center (NEIC) in Golden, Colorado.

The USGS is a committed partner in the National Earthquake Hazards Reduction Program, or NEHRP, which is led by the National Institute of Standards and Technology (NIST) and includes the Federal Emergency Management Agency (FEMA) and the National Science Foundation (NSF). That commitment involves collaboration going beyond the four agencies to include other Federal partners, State, Tribal and local governments, academic institutions, and the private sector.

We appreciate the opportunity to provide you with an update on the program. Federal, State, and local agencies have continued to work together closely since the appropriations authority for NEHRP expired in 2009. Understanding earthquake hazards, quantifying earthquake risk, and helping to build more resilient communities is a part of each of our missions.

NEHRP was founded on the belief that while earthquakes are inevitable, there is much that we can do as a Nation to improve public safety, reduce losses and impacts, and increase our resilience to earthquakes and related hazards. There is a technical distinction between "hazards," which are the physical phenomenon of the earth shaking, versus "risks," which are the potential consequences from that shaking. While earthquakes do happen all across the country, about 80 percent of the risk they pose is in California—50 percent just in southern California. Within NEHRP each agency performs a distinct and complementary role essential for the overall success of the program. It is conducted with a high degree of cooperation and collaboration, avoiding overlap and competition for responsibilities or resources. The heart of this partnership is a broadly shared commitment to translate the results of research, field studies, and seismic monitoring into implementation actions that can reduce earthquake losses.

The USGS role within NEHRP is to deliver the data and information tools that engineers, emergency managers, government officials, and the public need to prevent earthquake hazards from becoming disasters. USGS activities under NEHRP are implemented through the Earthquake Hazards Program and the Global Seismographic Network (see below). Along with its partners, the USGS provides rapid, authoritative information on the magnitude, location, shaking intensity and potential impacts of earthquakes, both in the United States and around the world. The Survey also develops national and regional hazard assessment maps and supports targeted research to improve these products. Lastly, the USGS works with a wide range of partners to help grow public awareness of earthquake hazards. I will share some examples of each of these activities and elaborate on the importance of NEHRP to making them possible.

As for the Global Seismographic Network, this Network enables fundamental geophysics research, and also supports national security objectives by monitoring and characterizing nuclear test detonations. It represents an important international component of NEHRP.

Earthquake information: The USGS NEIC, is a 24/7 operation, generating a broad suite of near-real time earthquake information products to provide situational awareness for emergency responders and the public. Over 409,000 users are signed up to receive USGS earthquake notifications. The Prompt Assessment of Global Earthquakes for Response, or PAGER alerts, provide rapid assessment of potential economic impacts and fatalities, while ShakeMap graphically depicts the intensity of shaking, which is useful for many applications, particularly post-event engineering assessments. These products are made possible by the earthquake monitoring networks that make up the Advanced National Seismic System (ANSS), including regional seismic networks that the USGS supports with its academic partners. Lastly, *Did-You-Feel-It?* is a widely used web-based crowd-sourcing tool that allows members of the public to describe their experience of an earthquake in a scientifically useful format. This citizen science data augments seismic data that the USGS collects from its monitoring networks. When you do feel an earthquake, please search for *Did-You-Feel-It?* online and provide the USGS with your own data.

Significant modernization improvements to the ANSS were made in 2010 and 2011, such as replacing outdated analog equipment and upgrading communications software. In FY18, we are continuing this by directing $5 million for deferred maintenance on the ANSS system and $23 million for the build-out of *ShakeAlert*, according to congressional direction. The ANSS includes instrumentation in buildings and other engineered structures to support research on their response to seismic shaking. The resulting data and models help structural engineers to design buildings with improved earthquake resistance. This Administration has emphasized the importance of infrastructure to our national economy, and the ANSS is one such example of critical scientific infrastructure.

Assessments of earthquake hazards: About 142 million Americans live in areas with moderate to high earthquake hazards. In addition to national assessments, the most recent of which the USGS published in 2014[1] and will update again in 2018, we also publish more detailed urban assessments. The most recent maps were published for St. Louis, following on urban seismic hazard maps prepared for Seattle and Los Angeles, and new maps are expected for Salt Lake City in the next few years. These assessments are based on models that incorporate the best available science about faults, and prehistoric and historical records. The assessments in turn are used to inform building codes and community planning. In 2017 the USGS incorporated induced seismicity hazards into an assessment of short-term hazard from earthquakes in the Central and Eastern United States. There is significant domestic energy development potential in this region, and better understanding of this phenomenon enables states and the private sector to develop methods for improving safety.

Targeted research: USGS research is supplemented by external research which the USGS supports through grants and cooperative agreements, and it serves as a bridge from fundamental research supported by NSF into applications by the USGS and its other NEHRP partners. The Southern California Earthquake Center (SCEC) is an example of such research partnerships. Led from the University of Southern California, SCEC has received support from both the USGS and NSF for over 25 years, fostering a new generation of earthquake researchers. In the next few years, we expect USGS-supported research to tell us more about earthquakes in Puget Sound, near Reno, Las Vegas and Lake Mead, and develop methods to rapidly estimate damage from liquefaction.[2]

Public awareness: All the best earth science cannot guarantee that people are able to use the information to make informed decisions that will keep their families, their businesses, and their communities safe. Since 2003, the USGS has supported publication of *Putting Down Roots in Earthquake Country*, now available for eight different regions, including Alaska, Utah, Nevada, and the Central United States. These publications provide information about the threat posed by earthquakes in their respective regions and explain how residents can prepare, survive, and recover from these inevitable events. They have also been translated into Spanish, Chinese, Vietnamese, and Korean. Since 2008, the USGS has supported the annual Great ShakeOut exercise, which I will mention below. Last year, several thousand organizations, including local governments, hospitals, schools, places of worship, and businesses, have signed up, representing 20 million participants in the United States.

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[1] USGS Open-File Report 2014-1091 available at https://pubs.er.usgs.gov/publication/ofr20141091

[2] 2018 research available at https://earthquake.usgs.gov/cfusion/external_grants/research.cfm

Close coordination among scientists, engineers, and emergency managers has clearly made the United States safer from earthquakes, however USGS offers several new considerations to improve the program going forward. For example, earthquake prediction was an original goal of the program, but is today considered scientifically unfeasible. Today, however it is possible for the USGS to issue early warnings of impending shaking from earthquakes that have already begun. Pursuant to USGS authority to develop an earthquake early system, Congress has appropriated funds in recent years to continue development of this system. The USGS is committed to working with Congress to determine the appropriate federal, state and local cost share associated with any future *ShakeAlert* developments.

Earthquake hazards here in California are well-known but, before I focus on California, I would like to highlight other earthquake hazards around the country. In recent decades, research[3] on the Cascadia Subduction Zone has highlighted the exceptional hazard in the Pacific Northwest. Subduction zones are areas where an oceanic tectonic plate is being forced under a continental plate thus forming a broad zone of seismic activity, in contrast to the plate boundary in most of California where the plates mainly slip horizontally. Subduction zones produce the largest earthquakes. For example, the Tohoku, Japan, earthquake of 2011 occurred on a subduction zone fault and it was over magnitude 9, making it one of the largest earthquakes ever recorded. Similarly, the largest recorded earthquake in North American history also occurred on a subduction zone fault off the coast of Alaska in 1964. These and other subduction zone earthquakes also have the potential to generate tsunamis that propagate across the ocean and can impact communities far from their epicenters.

Our Nation's exposure to earthquake hazards is not limited to the Pacific coast. Very large earthquakes have occurred in Virginia, South Carolina, Indiana, and the New Madrid zone in Missouri. The New Madrid zone deserves special mention. In 1811 and 1812, several earthquakes as large as 7.5 magnitude occurred there. At the time, human settlement in the area was relatively sparse, but today this represents an immediate hazard to over 200,000 people and a potential hazard to the Memphis region of 1.3 million people. Large earthquakes in this region happen infrequently, and most of the older buildings and infrastructure elements were not designed to resist strong shaking. In Delaware, in a region not previously known for active seismicity, a 4.1 magnitude earthquake struck in November 2017. This reminds us that earthquakes do happen nationwide.

Turning to California, since the great California earthquakes of 1868 and 1906 in the San Francisco Bay Area, we have learned much about earthquakes in California and translated that knowledge into better building codes, better emergency response plans and, in response to Congressional direction, into a world-class early warning system called *ShakeAlert*. We know that very large earthquakes happen here and, due to the complex nature of California's fault

[3] USGS Public Paper 1661-F available at https://pubs.usgs.gov/pp/pp1661f/

systems and geology, they have especially dangerous potential. While many critical pieces of infrastructure, such as hospitals, highway interchanges, and bridges, have been retrofitted to meet the highest earthquake engineering standards, other infrastructure has lagged, particularly the infrastructure of water and data distribution systems. Many seaports and some airports are built on land that is susceptible to liquefaction, where shaking causes the soil to temporarily lose strength and cohesion and flow laterally (temporarily behaving somewhat like quicksand). Additionally, there have been proposals to upgrade codes for residential and office buildings to make them not only "life-safe," that is, less likely to collapse, but also usable after the earthquake. This would reduce the time and costs of recovery and make communities more resilient.

The USGS has had an earthquake studies field office at Pasadena for over 40 years, working closely with partners at Caltech and elsewhere to develop and maintain state-of-the-art seismic and geodetic monitoring systems throughout southern California. The USGS has supported individual research projects at various academic institutions including Caltech, USC, UCLA, U.C. Irvine, U.C. San Diego and elsewhere. In 2017 the USGS commitment to these and other activities in the region was $4.5 million.

In northern California, the Hayward fault, which slices through the highly urbanized East Bay region, is one of the most dangerous faults in the state, with an estimated 1-in-3 probability of generating a damaging earthquake in the next 30 years. Last month, the USGS, along with approximately 60 partners, released a new assessment of such an earthquake, called the HayWired scenario.[4] It provides a realistic, highly detailed depiction of what may happen during and after a magnitude 7 earthquake with an epicenter in Oakland. This is an impact assessment, however, not a prediction. A real earthquake on the Hayward Fault could occur at any time and with a different pattern of shaking. Understanding the risk and getting ready for a large earthquake on the Hayward Fault like the one depicted in this scenario can help other at-risk communities prepare for similar events that are possible in their area. Overall, given the population and economic importance of California, and the known seismicity of the region, earthquake hazards remain a serious threat to all Californians' lives and livelihoods.

I would like to discuss a few other NEHRP activities that are of interest to Californians. The first and perhaps most relevant to California right now is the impending first stage roll out of *ShakeAlert*, the earthquake early warning system for the West Coast of the United States. Earlier, I called it "world-class" because the goal of the USGS and its partners is not to simply duplicate the early warning efforts of other countries, but to build the most advanced earthquake warning system in the world. To that end, Congress and the state of California have supported work to dramatically densify seismic and geodetic monitoring networks. Such dense network coverage is the backbone of *ShakeAlert*. The USGS has also worked with both public and

[4] USGS Scientific Investigation Report 2017-5013 available at https://pubs.er.usgs.gov/publication/sir20175013

private partners to develop notification delivery methods and automated response systems. For example, BART in northern California has integrated *ShakeAlert* into systems that automatically slow trains during earthquakes. Other users are developing similar operations for their infrastructure in many sectors including utilities, transportation, health care, and schools.

Cities and counties are also considering the best way to integrate early warning data into their own emergency response plans. Broad public notifications through wireless phones, similar to the weather alerts made possible by the NOAA National Weather Service, face technical challenges, but could possibly be available by the end of the year. Most importantly, when the first stage is announced, more users will be motivated to develop products and services to take concrete actions based on USGS early warning data, rather than only experimental or test actions. It is crucial that we roll out a system with minimal false alarms and that partners have done their due diligence to operationalize real-time seismic data. We want users to have confidence in the system and ensure that the USGS releases only the highest quality data and notifications. The long-term possibilities include an earthquake early warning across the West Coast, including Alaska.

Lastly, I want to remind the committee of the annual Great ShakeOut, which began in 2008 as part of a scenario for a major earthquake on the southern San Andreas Fault. This year's ShakeOut event happens on 10/18 at 10:18 am. People around the country and the world participate in drills to practice safe responses to an earthquake. Please consider enlisting your offices as participants at ShakeOut.org.

In summary, the Department of the Interior supports reauthorization of NEHRP, because it has been a successful interagency partnership that continues to make valuable contributions to the Nation's resilience to earthquakes and other hazards. On behalf of the USGS, thank you for this opportunity to testify today. I would be happy to answer any questions you may have.

Dr. Steve Hickman

Steve Hickman has been the Director of the USGS Earthquake Science Center since 2015. Among his accomplishments, he was Principal Investigator on the San Andreas Fault Observatory at Depth, a major component on the National Science Foundation's EarthScope project. He has also served as chair of the Science Advisory Group for the International Continental Scientific Drilling Program. Dr. Hickman received a bachelor's degree in geology from Earlham College and a PhD in solid-earth geophysics from MIT. His accolades include the Superior Service and Meritorious Service Awards from the Department of the Interior and the 2014 "Paul G. Silver Award for Outstanding Scientific Service" from the American Geophysical Union.

Mr. ROHRABACHER. Thank you very much for your testimony.
Dr. Vernon?

**TESTIMONY OF DR. FRANK VERNON,
RESEARCH GEOPHYSICIST,
INSTITUTE OF GEOPHYSICS AND PLANETARY PHYSICS,
SCRIPPS INSTITUTION OF OCEANOGRAPHY, UC SAN DIEGO**

Dr. VERNON. Chairman Rohrabacher, Representative Takano, and Representative McNerney, thank you for the opportunity to discuss the National Earthquake Hazards Reduction Program. My name is Frank Vernon. I am the Director of the USArray Array Network Facility, which is part of the EarthScope Program, and I work at the UC–San Diego Scripps Institution of Oceanography Institute of Geophysics and Planetary Physics.

I would also like to ask to have my written testimony entered into the record as the formal record, please.

Mr. ROHRABACHER. Without objection, and that will also be true for our other witnesses as well.

Dr. VERNON. Most of my career has been focused on developing distributed real-time sensor networks and autonomous sensor networks in terrestrial and marine environments. In 1982, in partnership with the USGS, we deployed the first digital seismic telemetry network in the U.S. on the San Jacinto Fault down here, what is known as the ANZA network. That network is funded by the USGS through NEHRP, through its instantiation in 1982, and then funding for that continued through 2014.

Another project that we have been working on is the EarthScope/USArray, which is the primary thing. USArray is a project that is the seismological component of the EarthScope program at NSF. The core of the USArray project was known as the transportable array comprised of 500 broadband seismic stations deployed at a nominal 70-kilometer grid bounded by the borders of the lower 48 states. Each station was deployed for about two years, enrolled from a manner from the West Coast to the East Coast starting in 2004 and completing in 2015.

After the TA completed work on the lower 48 in 2015, the project was divided into two parts. Under NSF funding, funding was secured to deploy approximately 280 stations in the State of Alaska, and that project was then slated to continue through 2019 and 2020, depending on which of the stations you are talking about.

Approximately 160 stations deployed in the TA have been transitioned into the Eastern U.S. seismic network, which started in 2014. CEUSN, as we call it, data streams have been integrated into the Advanced National Seismic System, the ANSS, and the operations are now being transitioned to USGS internal operations.

In my opinion, it was a missed opportunity when USArray TA was proposed that the USGS and NSF did not come up with a plan to transition all the TA sites into the ANSS permanent stations. If that had occurred, the 48 states would have approximately a 1,600-station network with a nominal 70-kilometer grid recording all earthquakes down to a magnitude 1.5 with completeness for the whole lower 48 states. With the current deployment in Alaska, there is still opportunity to decide to transition the TA stations into a permanent Alaska seismic network, a key component of the ANSS.

Another component of the USArray program was funded through the American Recovery and Reinvestment Act leveraging the existing permitting field program and telemetry to augment with infrasound and meteorological sensors. This is something that I think is very important. Those of us who are in the field side of things do a lot of work dealing with permits, dealing with access to sites, dealing with communications, dealing with networking, and we should be leveraging this much more broadly than we have historically been in the past.

For instance, the data that we put in these meteorological sensors that have been used are now available to the National Weather Service for incorporation into forecast models.

Overall, I think I would like to step back a bit and say the NEHRP program has been extremely beneficial towards our understanding of earthquakes and their related hazards. The strengths of the program are the partnerships between academic organizations, state agencies, and Federal NEHRP agencies, which has been remarkable. Based on my experience of deploying and operating seismic networks and field experiments under NSF and USGS funding, as well as conducting research on these data, I would like to make the following recommendations.

First is to keep a well-funded basic and applied research NSF program in earthquake engineering, the properties of earthquake sources, ground motion estimation, and other aspects of earthquake faulting, which will be key to make advances to understand the earthquake hazards and earthquake risks.

Second is to keep a sustainable Advanced National Seismic System, including continuing support for the existing eleven regional seismic network operators.

Next would be to support research at ANSS partner facilities that improves their ability to deliver accurate earthquake assessments and products. Each of these networks that operate in each of these regions has a much more specific knowledge where they are operating, whether it be Northern California or Alaska or Washington, wherever these other network operators are.

A thing that people might not think about is I think there is an opportunity to think about how to improve the permitting process of how we deploy these stations, because we have to deal across multiple agencies, whether it is Agriculture or Interior, and how do we set up a more standardized format instead of having it be regionalized by each district or national forest or national park, figure out a methodology to make that more efficient and make less friction in the process.

I think shared resources between agencies should be encouraged. For example, a seismic site is permitted and has telemetry; why not add to this investment by adding more sensors such as meteorological sensors that can be used by the National Weather Service or another project I am involved with, wildfire cameras in places that can provide information in those situations.

I would recommend that the Alaska TA be integrated into the Alaska Earthquake Center operations and into the ANSS, maybe using some partnership with NASA and NOAA. There are some opportunities there that might be useful because the data are used for multiple agencies.

And finally, I would like to echo the recommendation of the Scientific Earthquake Studies Advisory Committee in keeping equal amounts of resources towards research as well as towards the network operations.

In closing, I would like to thank the Committee for the opportunity to testify on the review of the Federal National Earthquake Hazards Reduction Program and say that hazard and risk reduction is more important now than ever before considering how much we have built up our environment.

Thank you.

[The prepared statement of Dr. Vernon follows:]

WRITTEN TESTIMONY OF

Dr. Frank Vernon
Director, USArray Array Network Facility
Scripps Institution of Oceanography
University of California San Diego

BEFORE THE UNITED STATES HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

FIELD HEARING TO REVIEW THE FEDERAL NATIONAL EARTHQUAKE HAZARDS REDUCTION PROGRAM (NEHRP)

May 31, 2018
Huntington Beach, CA

Introduction

Chairman Rohrabacher and members of the Committee, thank you for the opportunity to be here today to discuss the National Earthquake Hazards Reduction Program. My name is Frank Vernon and I am the Director of the USArray Array Network Facility at University of California San Diego's Scripps Institution of Oceanography (Scripps), where I also received a Ph.D. in Geophysics. I have many years of experience as a seismologist leading basic and applied research programs around the globe.

Most of my career has been focused on developing distributed networked real-time and autonomous sensor networks in terrestrial and marine environments. In 1982, in partnership with the USGS, we deployed the first digital telemetry network in the US along the San Jacinto Fault in southern California, known as the ANZA network. Its mission was and still is to provide high quality research data while supporting real time monitoring and now earthquake early warning requirements. As the technology base supporting ANZA evolved, it was used as the foundation of systems to provide in-country monitoring of the Soviet and US nuclear test sites (1987-1988), earthquake monitoring in Kyrgyzstan (1991-2000), multiple telemetry arrays under the Incorporated Research Institutions for Seismology (IRIS) (1991-2003), and USArray (2003-present). These programs received support from multiple federal agencies including the NSF, USGS, DOD, and DOE. Since 2010 I have been a PI on very dense seismic deployment around the San Jacinto fault zone, focusing on earthquake source physics, fault structure, and providing real-time seismic monitoring capability for southernmost California.

Based on evolving new telemetry technologies and requirements, Han-Werner Braun and I started the HPWREN program (2001-present) creating a large-scale wireless high-performance data network that is being used for interdisciplinary research and education applications, as well as a research test bed for wireless technology systems in general. Originally funded by NSF and now self-sustaining, HPWREN provides wide area wireless internet access throughout southernmost California including remote regions of San Diego, Riverside, and Imperial counties and the offshore regions primarily serving environmental sensor networks and public safety. Under UC San Diego's HPWREN program, research being conducted on building "last kilometer" wireless links and developing networking infrastructure to capture real-time data from multiple types of sensors from seismic networks, hydrological sensors, oceanographic sensors, wildfire cameras, meteorological sensors, as well as data from coastal radar and GPS.

My testimony is organized as follows: 1. NSF Funded Earthquake Research At UCSD; 2. USGS Seismic Monitoring; and 3. Closing recommendations.

NSF Funded Earthquake Research At UCSD

NEHRP

At the present time, UC San Diego has four active NSF-NEHRP Funding grants providing a total of $4.3M spanning 2016-2020. All the active NSF grants are through Division of Civil, Mechanical, and Manufacturing Innovation part of the Directorate of Engineering.

The Natural Hazards Engineering Research Infrastructure (NHERI) is supported by the National Science Foundation (NSF) creating a distributed, multi-user national facility that provides the natural hazards research community with access to research infrastructure that includes earthquake and wind engineering experimental facilities, cyberinfrastructure, computational modeling and simulation tools, and research data, as well as education and community outreach activities. This includes the *Experimental Facility with Large, High Performance, Outdoor Shake Table* (LHPOST), operated by the UC San Diego Jacobs School of Engineering, to support research in structural and geotechnical earthquake engineering (Prof. Joel Conte, Principal Investigator).

LHPOST is used for research in large structures by many different universities. Two of these NSF funded research projects are led by faculty at the UC San Diego Jacobs School of Engineering. One of these projects, *Collaborative Research: Seismic Resiliency of Repetitively Framed Mid-Rise Cold-Formed Steel Buildings* (Prof. Tara Hutchinson, Principal Investigator), is investigating the response of cold-formed steel building systems under earthquake loads. Cold-formed steel buildings potentially will have low installation and maintenance costs with high durability. The second project, *Collapse Simulation of Shear-Dominated Reinforced Masonry Wall Systems* (Prof. P. Benson Shing, Principal Investigator), will obtain experimental data to understand the behavior of Reinforced Masonry wall structures up to the point of collapse, and then will use the data to advance and validate analytical modeling capabilities.

Between 1990 and 2016, UC San Diego has completed 35 NSF-NEHRP funding grants with a combined total of $15.3M. The completed NSF grants were through either Division of Civil, Mechanical, and Manufacturing Innovation under the Directorate of Engineering, or from the Division of Earth Sciences component of the Directorate of Geosciences.

Division of Earth Sciences

There are many projects that research earthquakes and earthquake faults that are not directly part of the NEHRP program. However, the research results are used to inform NEHERP from ground motion estimation, seismic hazard, earthquake fault structures, and earthquake source physics. One of these projects that I was a Principal Investigator on was the *NSF/CD: Collaborative Research: Structural Architecture and Evolutionary Plate-Boundary Processes along the San Jacinto Fault Zone*, a collaborative project led by USC (Y. Ben-Zion), with UCSD (myself and Y.

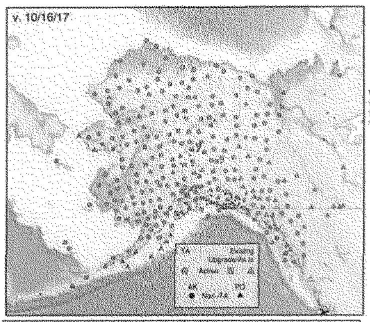
Fialko), SDSU (T. Rockwell), Georgia Tech (Z. Peng), and UNAVCO (D. Mencin). The goal of this large multi-institutional project was to examine the dynamics associated with earthquake rupture. The studies carried out are providing much more comprehensive constraints on the way that a major fault zone behaves. Specifically, the project combines detailed imaging of the San Jacinto Fault (SJF) in Southern California using multiple seismic arrays to characterize the fault zone in the subsurface. It couples this with surface outcrop and mapping of the fault zone, paleoseismic analysis, GPS analysis of crustal deformation, and theoretical work on seismic propagation to understand how factors such as fault damage, juxtaposition of different rock types, and segmentation affect the behavior of the fault zone. The long-term goal of this type of research is to bring together current ideas about the rupture process and outline an approach that may be able to provide a quantitative understanding of the evolution of fault zone structures and related deformation phenomena (seismicity, strain fields) in actively deforming regions.

In the late Spring of 2014, as part of the San Jacinto project, we had the opportunity to deploy the first complete academic "Large N" experiment to observe the unaliased two dimensional seismic wavefield. This experiment deployed 1108 high frequency instruments in an area 600 meters by 600 meters, spanning the surface trace of San Jacinto Fault at Sage Brush Flats. This is a new methodology being introduced into earthquake seismology, which is enabled by the technological advancement of petroleum industry instrumentation. Researchers at Caltech, were the first to analyze earthquake and ambient noise data from an oil industry survey in Long Beach. Our experiment was the first of this type where the target was the structure of a tectonic fault (instead of an oil field). This was the beginning of a rapidly developing integration of emerging geophysical industry techniques with advances of continuous earthquake monitoring to address earthquake research questions.

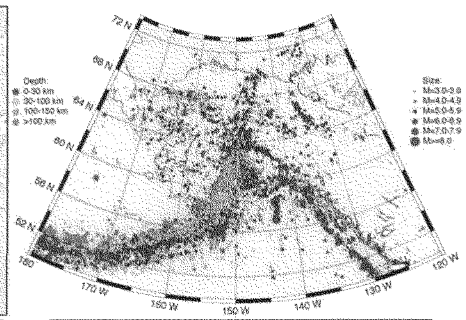
EarthScope/USArray

The USArray project is the seismological component of the NSF EarthScope program. The core of the USArray project is known as the Transportable Array (TA) comprised of ~500 broadband seismic stations deployed in a nominal 70 km grid bounded by the borders of the lower 48 states. Each station was deployed ~2 years and the TA was moved in a rolling manner to the east. EarthScope was started in 2003 as a MREFC and transitioned to operations and maintenance in 2008. Under my direction, Scripps operates the USArray Array Network Facility and is responsible for: the data acquisition and delivery from all Transportable Array stations (~500 at full deployment) to the national archive at the IRIS Data Management Center; station command and control; verification and distribution of metadata; providing useful interfaces for personnel at the Array Operations Facility to access state of health information; and quality control for all data. Data are acquired over multiple types of communication links including wireless, satellite, and wired networks. Many researchers and students domestically and internationally have written hundreds of refereed journal articles and hundreds of Ph.D. theses based on TA data.

After the TA completed work in the Lower 48 in 2015, the project was divided into two parts. Under NSF funding, funding was secured to deploy approximately 280 TA stations in Alaska until 2019. All stations are now in the ground, including 72 cooperating stations from existing networks operated largely by the Alaska Earthquake Center but also including stations operated by Alaska Volcano Observatory, National Tsunami Warning Center, and Canadian Hazard Information Service. The array is a grid of stations spaced about 85 km apart covering all of mainland Alaska and parts of the Yukon, British Columbia, and the Northwest Territories (Figure 1). The focus of the Alaska deployment is to use local, regional, and teleseismic earthquakes to improve our understanding of Earth structure and earthquake activity in Alaska.

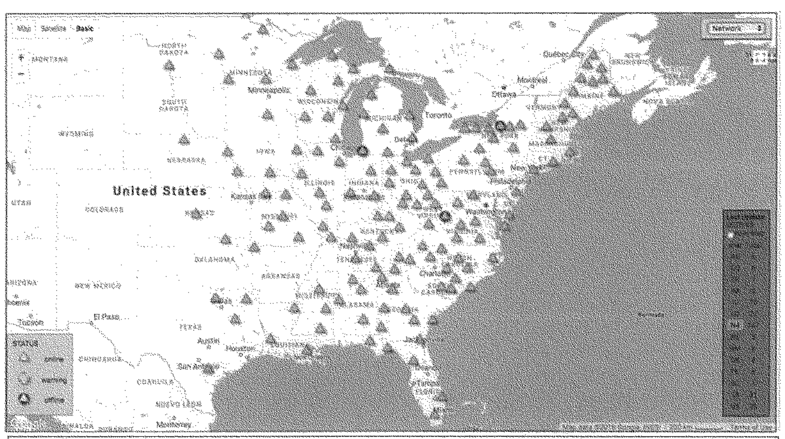


Currently locations of the USArray Transportable Array including contributed stations from other networks. Figure curtesy of Robert



Seismicity from 1970-2012 and vicinity from the Alaska Earthquake Center and the USGS PDE catalogs. Figure curtesy of Natasha Rupert (AEC)

Approximately 160 deployed stations of the TA were transitioned into the Central and Eastern US Network (CEUSN) starting in 2014. CEUSN data streams have been integrated into the Advanced National Seismic System (ANSS) and the operations are now being transitioned to USGS internal operations.



Map of the former TA/CEUSN seismic stations currently transitioning to the Advanced National Seismic System.

The transition of TA stations into permanent CEUSN/ANSS seismic stations is a positive outcome leveraging the permitting, siting, construction, installation, and field equipment under the TA and providing much needed enhanced coverage throughout the eastern US. In my opinion, it was a missed opportunity when the USArray TA was being proposed, that the USGS and NSF did not come up with a plan and budget to transition all TA sites into ANSS permanent stations. If this had occurred, the lower 48 states would have ~1600 stations providing coverage on a nominal 70 km grid recording all earthquakes in that region with magnitude 1.5 and above. With the current TA deployment in Alaska, there is still the opportunity to decide to transition the TA stations into the permanent Alaska Seismic Network, a key component of the ANSS.

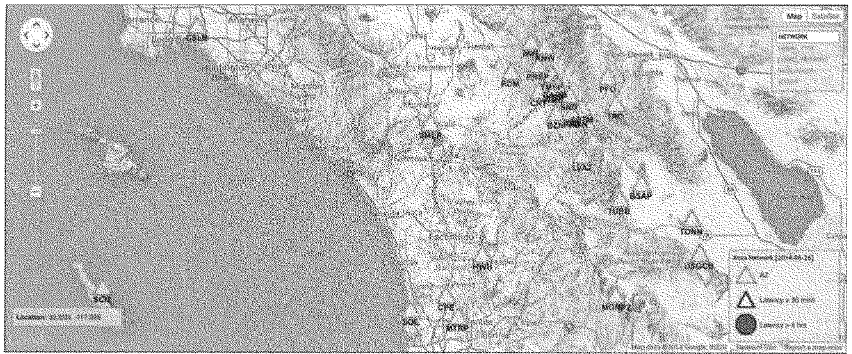
Another offshoot of the USArray TA was funded through the American Recovery and Reinvestment Act leveraging the existing permitting, field program, and telemetry to augment sites with infrasound and meteorological sensors. The NSF project, *MRI-R2: Acquisition of a Semi-Continental Scale Atmospheric Acoustic Transportable Array* (PIs: F. Vernon, M. Hedlin) created a real-time infrasound array whose sensing elements are co-located with the 400 seismic stations in the USArray Transportable Array component of the NSF EarthScope program. This continuously sampled array, of an unprecedented scale, provides opportunities for groundbreaking and interdisciplinary research in atmospheric acoustics, atmospheric science, and seismology. The dense network of infrasound sensors allows us to study the nature of long-range infrasound propagation from regional to continental distances and study the sources of infrasound signals. Over the past few years we also have been able to augment the TA with meteorological sensors from a variety of funding sources. Now, essentially all TA stations in Alaska are providing near real time data meteorological data in addition to the core seismic mission. These stations are predominantly in extremely remote areas that had no prior coverage. These data are made available to the National Weather Service for incorporation into forecast models.

USGS/ANSS Seismic Monitoring

ANZA Seismic Network

In 1982 I started my Ph.D. research project, building the ANZA seismic network to study earthquakes along the San Jacinto fault in southern California. The ANZA seismic network originally was a joint USGS-UCSD project and was the first earthquake digital telemetry network. The ANZA network is still operational today having kept pace with evolving technology to monitor local and regional seismicity in southern California. The network provides real-time data to the ANSS, the California Integrated Seismic Network (CISN), and the greater San Diego community. The ANZA seismic network was funded by the USGS since its initiation in 1982 until 2014 through NEHRP. Since 2014 the ANZA network has survived on private funds and internal UCSD funds. The ANZA seismic network continues to freely provide real time data to CISN and ANSS, as an external network to both organizations. More than 20 Ph.D. theses and 100+ refereed journal articles have been based on ANZA data.

The ANZA seismic network currently consists of twenty-eight operational stations. Most of the stations are located along the San Jacinto fault starting with IWR and RDM towards the top of the map, and TONN and USGCB on the right side of the map. The San Jacinto fault is one of the two most dangerous faults in southern California, the other being the San Andreas Fault.



Map of the ANZA Seismic Network stations.

Advanced National Seismic System

According to the USGS Circular 1429 *Advanced National Seismic System Current Status, Development Opportunities, and Priorities for 2017–2027*, the ANSS is a collaboration of federal, state, and academic partners. The role of the ANSS includes immediate earthquake notifications to governments and emergency managers, determining earthquake source characteristics, and providing ANSS websites with real-time earthquake information, a suite of real-time situational awareness products, a catalog of information (the ANSS Comprehensive Catalog), and products for engineers served by the Center for Engineering Strong Motion Data. Currently there are approximately 3000 ANSS stations operated by eleven regional seismic networks and the USGS. Total funding for the ANSS from the USGS Earthquake Hazards Program in fiscal year (FY) 2016 was $30.8 million, including $8.2 million for the implementation of earthquake early warning on the west coast.

One ongoing issue is the balance of research and operations under the USGS Earthquake Hazards Program. The *Scientific Earthquake Studies Advisory Committee Report 2017-2018* states that

> "SESAC reaffirms its principle that monitoring should not consume more than 50% of the EHP budget. The momentum of ShakeAlert (EEW) presents a challenge now and will present an even greater challenge in the future. Earthquake early warning resonates with the public and Congress. It exists as a product of the modernization of the ANSS plus regional networks. It will require more resources as EEW continues to expand. Implementation for a similar system elsewhere in the US would be impossible to meet with current funding levels. It is easy to forget/ignore that products like EEW are founded on solid, basic science into the nature of earthquakes. This fundamental understanding of earthquake science comes from highly-trained people dedicated to their work, not from instruments and technology. There is a diverse body of research (seismology, geology, geodesy, laboratory) that must be integrated to understand the nature of earthquakes and quantify the available data in order to deliver successful products. The success of the EHP

has been its ability to merge monitoring and research. As earthquake monitoring grows, earthquake hazard assessment and earthquake research must grow in equal measure."

At present the ANSS is about 40% of its original design goals. Current funding levels are sufficient to maintain current operations but are insufficient for addressing the future needs of earthquake early warning, as well as the future needs monitoring of urban areas, critical facilities, and structures. A significant increase in funding to the NEHRP funding will be needed to achieve the goals of the ANSS with earthquake early warning capabilities and to sustain the research needed to reach these goals.

Closing recommendations

Overall the NEHRP program has been extremely beneficial towards our understanding of earthquakes and their related hazards. The strengths of the program are the partnerships between academic organizations, state agencies, and federal NEHRP agencies.

Based on my experience of deploying and operating seismic networks and field experiments under NSF and USGS funding, as well as conducting research on these data, I would like to make the following recommendations for NEHRP.

1. Keeping a well-funded basic and applied research NSF programs in earthquake engineering, the properties of earthquake sources, and ground motion estimation will be key for making advances in understanding earthquake hazards and earthquake risks.
2. Keep a sustainable Advanced National Seismic System including continuing support for the existing eleven regional seismic network operators.
3. Support research at ANSS partner facilities that improves their ability to deliver accurate earthquake assessments and products;
4. Permitting – Set up a streamlined expedited process for deploying earthquake monitoring sites across federal agencies. Permitting is extremely expensive and time consuming and significant cost savings could be achieved by simplifying and shortening the process. Language similar to Senate Bill 1768 is needed
   a. *''(V) Coordinating with the Secretary of Agriculture and the Secretary of the Interior on the use of public lands for earthquake monitoring and research stations, and related data collection.''*
5. Shared resources between agencies should be encouraged. For example, if a seismic site is permitted and has telemetry, why not leverage this investment by adding other sensors such as meteorological sensors that can be used by the National Weather Service.
6. Integrate Alaska TA into Alaska Earthquake Center Operations and hence into the ANSS.
7. Keep equal amounts of resources for monitoring and research in the Earthquake Hazard Program budget as Scientific Earthquake Studies Advisory Committee recommends.

In closing, I would like to thank the Committee for the opportunity to testify on the review of the federal National Earthquake Hazards Reduction Program.

Short Bio for Frank Vernon

Dr. Vernon is a Research Geophysicist at the Institute of Geophysics and Planetary Physics, Scripps Institution of Oceanography, University of California at San Diego (http://scrippsscholars.ucsd.edu/flvernon). His current research interests are focused on developing distributed networked real-time sensor networks in terrestrial and marine environments. Currently he is the Director for the USArray Array Network Facility for the NSF EarthScope program (http://anf.ucsd.edu). This network currently has over 500 stations using seismic, acoustic, and atmospheric pressure sensors delivering real-time data to UCSD, which are redistributed to multiple sites. The ANF is responsible for real-time state-of-health monitoring for the network in addition to the real time data processing, archiving, and distribution. Data are acquired over multiple types of communication links including wireless, satellite, and wired networks.

Dr. Vernon is the PI on the ANZA broadband and strong motion seismic network that has operated since 1982 providing real-time seismic monitoring capability for southernmost California (http://eqinfo.ucsd.edu). Dr. Vernon is a PI on very dense seismic deployment around the San Jacinto fault zone, focusing on earthquake source physics, fault structure, and providing real-time seismic monitoring capability for southernmost California. In addition Dr. Vernon is PI on the HPWREN program creating a large-scale wireless high-performance data network that is being used for interdisciplinary research and education applications, as well as a research test bed for wireless technology systems in general (http://hpwren.ucsd.edu). HPWREN provides wide area wireless internet access throughout southernmost California including San Diego, Riverside, and Riverside counties and the offshore regions. Under UCSD's HPWREN program, research being conducted on building "last kilometer" wireless links and developing networking infrastructure to capture real-time data from multiple types of sensors from seismic networks, hydrological sensors, oceanographic sensors, wildfire cameras, meteorological sensors, as well as data from coastal radar and GPS.

Dr. Vernon obtained a B.A. in Physics with Specialization in Earth Sciences from UCSD in 1977, and a Ph.D. in Earth Sciences from UCSD in 1989. He is author or co-author on more than 130 scientific articles and is currently editor for the AGU Earth and Space Sciences Journal.

Mr. ROHRABACHER. Thank you very much.
Mr. Poland?

TESTIMONY OF MR. CHRIS D. POLAND, CONSULTING ENGINEER; NIST COMMUNITY RESILIENCE FELLOW

Mr. POLAND. Mr. Rohrabacher, Mr. Takano, and Mr. McNerney, thank you very much for the opportunity to speak here today on behalf of the American Society of Civil Engineers. My name is Chris Poland. I am a licensed civil and structural engineer with over 40 years of experience and professional practice in structural engineering and earthquake engineering.

I am the NIST Community Resilience Fellow, and my testimony today represents the interests also of the Earthquake Engineering Research Institute.

NEHRP, now embodied in the public law, remains a solid foundation for the continued advancement of seismic safety and resilience for the nation. Over the past 40 years the program has sponsored extensive research addressing all facets of earthquake science and engineering. Its fundamental strength rests in its longevity, continuous funding, and the cooperative efforts of the four NEHRP agencies.

As both the leader within the NEHRP program and a consumer of the information in my engineering practice, I can say without reservation that the program is a success, fulfills a critical need, and has made great strides in advancing the science and engineering related to earthquakes.

For example, the NEHRP development of a technically complex retrofit standard for existing buildings has reduced the cost of implementing California's 30-year hospital retrofit program by billions of dollars. The money is saved by the buildings that don't need to be retrofit and the amount of retrofit that needs to be done. It is a huge, huge contribution.

The nation continues to be significantly better prepared to deal with the impact of strong earthquakes, and the program needs to continue pursuing all of its activities.

Unfortunately, the program has not yet accomplished all that was envisioned due to chronic underfunding of the four NEHRP agencies. The program has also not been reauthorized since 2004, and annual appropriations equal less than a third of the needed $306.5 million annually recommended by the National Research Council. Together, the lack of sufficient funding and reauthorization have weakened the program's overall effectiveness. This comes at a time when the nation's earthquake risk continues to grow due to the population growth, urban development, and deteriorating conditions of the built environment.

What do you need to do? We need to provide more funding. Since the last reauthorization, the focus of the earthquake engineering has broadened from concentrating on design and construction of individual buildings and infrastructure to also include an assessment of what is needed to make communities more resilient; that is, give them the ability to rapidly recover from severe seismic shocks. This broadens the focus and the challenges that NEHRP faces, and it needs to expand its research programs in all areas.

Congress needs to signal their support and broaden NEHRP to address community resilience and provide sufficient additional authorization for funding in the following four areas.

First, identify the existing gaps in seismic safety and community resilience through a nationwide risk assessment. A fundamental assessment of the nation's earthquake risk reduction will refine the direction the program is going, stimulate collaborative efforts between the agencies, establish the needed funding levels, and the need for additional statutory responsibilities. This is important after 40 years to really understand where we are today.

Second, develop community-based seismic hazard maps to find potential for strong shaking, faulting, landslides, and liquefaction on a block by block community scale. These are micro maps that we need. These maps are needed immediately, will require significant new scientific research, and are best developed at a national level by USGS to assure consistency and use of latest scientific findings. We have to have this block by block information to overlay with all the other information communities have so they can understand what their needs are for community resilience.

Third, complete the Advanced National Seismic System Monitoring Network for recording earthquakes and issuing early warnings throughout the nation. All earthquake professions use information derived from the seismic monitoring, and the emergency management community will eventually use early warning to save lives, reduce damage, economic disruption and business downtime, and to reduce psychological trauma.

Monitoring provides information that we all use, and it is extremely important. When we don't complete the ANSS program, we deny ourselves the opportunity to learn from the earthquakes as they occur. Earthquake warning is an extremely exciting opportunity. It comes with the ability to gather all this information that we need from earthquakes. It needs to be completed, and not in 20 years.

Development of a new generation of seismic standards for new and existing construction of buildings and lifeline infrastructure systems is the fourth key aspect. FEMA initiated the development of a functional recovery-based design and planning code from within a reauthorized NEHRP. It should be based on the work of a committee of experts who will set the appropriate hazard levels and performance goals for all buildings and lifeline infrastructure systems consistent with the Community Resilience Planning Guide for Buildings and Infrastructure Systems published by NIST in May of 2016. A rating system for easily identifying and publishing the anticipated seismic performance of individual buildings should also be developed and implemented.

It is a new generation code that we need, and it takes a fresh start to get there. Fortunately, the current bipartisan Senate bill, S. 1768, the National Earthquake Hazards Reduction Program Reauthorization Act, includes these critical additions to NEHRP.

Thank you so much for the opportunity to share my views with the Committee from the trenches, if you will, down where the people are, where the buildings are. Regarding NEHRP, I urge Congress to move quickly to reauthorize this critical program with these outlined improvements, and I am happy to answer any questions that you have.

[The prepared statement of Mr. Poland follows:]

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Testimony before the Congress of the United States
House of Representatives
Committee on Science, Space, and Technology

Chris D. Poland, PE, SE, NAE, M.ASCE, F.SEI
Consulting Engineer, NIST Community Resilience Fellow
Member, National Academy of Engineering

On behalf of the
American Society of Civil Engineers

May 31, 2018
Huntington Beach, California

Summary of Testimony

Over the past 40 years, the National Earthquake Hazard Reduction Program (NEHRP) has sponsored extensive research addressing all facets of earthquake science and engineering including characterizing the prevalent seismic hazards threatening the nation, monitoring programs to determine the frequency and severity of strong shaking, sponsoring the on-going development of hundreds of design guides and standards for buildings, and assisting states with preparedness and mitigation activities. Its fundamental strength rests in its longevity, continuous funding, and the cooperative efforts of the four NEHRP agencies; the National Institute of Standards and Technology (NIST), the United States Geological Survey (USGS), the Federal Emergency Management Agency (FEMA), and the National Science Foundation (NSF). As both a leader in NEHRP and a consumer of this information in my engineering practice for over 40 years, I can say without reservation that the program is a success, fulfills a critical need, and has made great strides in advancing the science and engineering related to earthquakes. The nation is significantly better prepared to deal with the impact of strong earthquakes because of the NEHRP.

Unfortunately, the program has not yet accomplished all that was envisioned due to chronic underfunding of the four NEHRP agencies. The program has also not been reauthorized since 2004 and annual appropriations equal less than a third of the needed $306.5 million annually recommended by the National Research Council in 2011. Together, these issues have weakened the program's overall effectiveness in the recent past and going forward. This comes at a time when the nation's earthquake risk continues to grow due to population growth, urban development, and the deteriorating condition of the built environment, (ACEHR 2017).

Since the last re-authorization of NEHRP in 2004, the focus of earthquake engineering has broadened from concentrating on the design and construction of individual buildings and infrastructure systems to also include an assessment of what is needed to make communities more resilient—the ability to rapidly recover from a severe seismic shock. This broadened focus challenges NEHRP to expand its research programs to include the characterization of community specific hazards, complete our seismic monitoring capabilities, and address the socioeconomic and cultural aspects and needs of the United States. New performance-based guidelines and standards that consider the social and economic needs of communities and the performance of buildings and lifeline infrastructure systems (power, transportation, communication, water and waste water systems) needed for rapid and efficient recovery need to be developed. Congress needs to broaden NEHRP and provide sufficient funding to protect the lives, property, and prosperity of the American people (ACEHR 2010). The current bi-partisan Senate bill, S. 1768 the National Earthquake Hazards Reduction Program Reauthorization Act, includes these critical additions to NEHRP.

Founded in 1852, ASCE is our nation's oldest civil engineering organization representing more than 150,000 civil engineers in private practice, government, industry and academia. ASCE is a 501(c)(3) non-profit educational and professional society.

Written Testimony

Chairman Smith and honorable members of the committee, thank you for the opportunity to speak here today on behalf of the American Society of Civil Engineers (ASCE) about the need to re-authorize the National Earthquake Hazard Reduction Program (NEHRP). My name is Chris D. Poland. I am a licensed Civil and Structural Engineer with over 40 years of experience in structural and earthquake engineering and a NIST Community Resilience Fellow. My testimony also represents the interests of the Earthquake Engineering Research Institute (EERI) where I currently serve as the Public Policy Advisory Committee Co-chairman. EERI, ASCE, the Seismological Society of America, and others in the earthquake community were active contributors to S. 1768.

Defining and achieving a disaster-resilient nation is at the heart of my technical interests and the main focus of my endeavors related to advancing the profession. My activities are focused on public safety related to earthquakes, earthquake engineering, and community resilience. My efforts began by helping professional society committees write seismic codes for buildings and other structures, and quickly grew to include leadership positions in many of the related professional societies. In addition to my professional practice in structural engineering, I have participated in a wide variety of research projects that have led to new processes and procedures, design guidelines, and standards that are cited by building codes. Since 2004, my efforts have taken on a broader perspective that reach beyond the technical aspects of earthquake engineering to include understanding public policies aimed at disaster resilience. By working with the business community, public policy groups, and becoming a vocal advocate for disaster resilience at the local level, I helped start the conversation for how to achieve a disaster-resilient San Francisco that has led to my active participation in the NIST Community Resilience Initiative as a Community Resilience Fellow. That initiative has generalized the process so that it applies to all hazards affecting all regions of the nation.

The NEHRP now embodied in the Public Law (42 USC 7701 *et.seq*) remains a solid foundation for the continued advancement of seismic safety and resilience for the nation. It clearly recognizes the nationwide vulnerabilities, the potential for loss of life, injury, destruction of property and the need for and benefits of developing federally sponsored earthquake hazard reductions measures. The NEHRP purpose is to reduce the risks of life and property from future earthquakes. The program' objectives include educating the public, developing design and construction methods, characterizing seismic hazards, developing model building codes, disseminating methods for mitigating risks, and developing ways to assure the availability of earthquake insurance.

Through the re-authorization process, the law needs to be amended to recognize that the built environment in earthquake-prone regions of the nation has been generally designed and constructed to protect human life without consideration of the time it will take to repair and recover from the damage. The law also must recognize that authorization levels need to be set in recognition of the $306.5 million annual need established by the National Research Council Report *Strategic Plan for the National Earthquake Hazard Reduction Program* (NRC 2011). The reauthorization should also broaden the program's objectives to focus on creating a built environment that supports community resilience through the development of performance-based design codes, guidelines and tools based on acceptable recovery times that have been established for the functions they serve.

The NEHRP programs that are now in the law need to be continued as the new demands of community resilience are added. The term "community resilience" means the ability of a community to prepare and plan for, absorb, recover from, and more successfully adapt to adverse events. Resilience starts at the local level, with individuals, families, and businesses, and the resilience of the built environment is part of the challenge. Resilience must also encompass the socio-economic and cultural aspects and needs of communities. (ACEHR 2010).

To address the broader focus on community resilience, NEHRP should be re-authorized to include the following.

1. **Identification of the gaps in seismic safety and community resilience through a nationwide risk assessment.**

   Broadening the NEHRP to address community resilience in a comprehensive way requires an enhanced level of collaboration among the NEHRP agencies. As the concepts of community resilience have developed over the past 10 years, various efforts have been added to the Agency programs, though not necessarily in a collaborative manner. To move forward in an efficient manner, a fundamental assessment of the nation's earthquake risk reduction process must be conducted to identify the gaps in knowledge, implementation, and mitigation activities that are delaying the improvement of national earthquake resilience. The assessment should be comprehensive and address the steps currently being taken by government at all levels and the private sector related to the built environment as well as efforts to address the potential social and economic impacts. This assessment will refine the direction of the program going forward, stimulate collaborative efforts between the agencies, establish the needed funding levels, and the need for additional statutory responsibilities (ACEHR 2015).

2. **Development of community based seismic hazard maps defining the potential for strong shaking, faulting, landslides, and liquefaction on a community scale.**

   Under the leadership of USGS, the earth science community has developed a scientifically defendable characterization of the seismic hazards across the United States. This is one of the most significant contributions by NEHRP to the seismic design of the built environment. This process is ongoing and needs sufficient funding to continue to refine the understanding and characterization of earthquakes. Those efforts will impact the design and rehabilitation of every element of the built environment and are needed to reduce uncertainty and improve cost expectations.

Earthquake characterizations are available now to support the work of earthquake engineers related to individual projects but generally not available to communities in map form (Geographic Information Systems (GIS) based). Community resilience planning for earthquakes is best served by understanding the seismic hazards (strong shaking, faulting, landslides, and liquefaction) in the community on a block by block basis (NIST GB 1 2016). The needed GIS databases and maps are available for strong shaking estimates but not for the other hazards. These are needed immediately and are best developed at the national level by USGS to assure consistency across community lines and access to the latest scientific findings.

3. **Completion of the Advanced National Seismic System (ANSS) Seismic monitoring network for recording earthquakes and issuing early warnings throughout the nation.**

The Advanced National Seismic System (ANSS) is an on-going program to modernize, expand, and integrate the nations monitoring networks. It was initiated over 10 years ago, has established the backbone of its system, and has accomplished 42 percent of its instrumentation goal, but it lacks sufficient funds to be completed. All earthquake professions use information derived from seismic monitoring. Earthquake scientists focus on understanding the source and nature of strong shaking based on the strong and weak motion recordings they obtain. Structural Engineers and their related design professional colleagues use strong motion records to better understand the behavior of the built environment, determine its damage potential under strong shaking, and fine-tune their designs to meet community needs. Economists and policy analysts focus on determining the appropriate framework for evaluating the benefits and cost effectiveness of mitigation efforts. Insurance professionals and their loss estimation consultants use the information to determine the expected dollar losses that could occur (NRC 2006). The emergency management community uses it to define scenario events for planning activities and will eventually use early warning to save lives, reduce damage, economic disruption and business downtime, and reduce psychological trauma (USGS 2014).

Completion of the Advanced National Seismic System will vastly improve the information learned from future earthquakes, reduce the uncertainly in the hazard characterizations, reduce the overall cost of achieving resilience, and complete the full development and deployment of the Earthquake Early Warning system. Additional authorization of funding and cooperation from the Secretary of Agriculture and Secretary of the Interior is needed to assist and expedite approvals for using public land for locating seismic monitoring instruments.

4. **Development of a new generation of Seismic Standards for New and Existing Construction of Buildings and Lifeline Infrastructure Systems.**

The International Code Council publishes 15 model building codes (I-Codes) that regulate the design and construction of buildings when adopted by local jurisdictions.

They are published on a 3-year cycle and used throughout the United States. The codes are developed by the engineering professions and significant changes are added during each cycle related to resilient construction. While this is a move in the right direction, these additions are focused on improving individual building's performance and are not addressing what is needed to accelerate community-wide recovery after a significant earthquake.

While there are many codes, standards, and guidelines that govern the design and construction of lifeline infrastructure systems, their focus relates to normal day-to-day operations of the system's components and do not cover the overall system's performance during earthquakes or the dependencies that exist between systems. More emphasis on risk reduction, system restoration, and societal impacts is needed along with unified performance and restoration goals across all systems. Extensive research and a new generation of codes, standards, and guidelines are needed (ATC 2016).

In an ideal community, all buildings and infrastructure systems would recover rapidly from a strong earthquake with little interruption in services. Buildings would remain usable, infrastructure systems would remain operational, and only a few days would be needed to clean up the mess and get back to normal operations. Unfortunately, this is not the case. Buildings and infrastructure systems of any mature community have been built over generations and are subject to changing demands, retrofit or mitigation needs, and deterioration. Design codes for new buildings and retrofit codes for existing buildings do not include the performance goals needed for community resilience. Lifeline Infrastructure Systems are not regulated by national codes and are designed to performance criteria set by their owners and often without regard for the needs of the community after a strong earthquake. In addition, most existing buildings and supporting infrastructure systems do not meet current minimum code requirements and are unlikely to contribute to community resilience in their existing condition.

Fortunately, every building and infrastructure system is not immediately needed for a community to recover efficiently. Buildings only need to be usable when needed to support recovery. For example, hospitals are needed immediately to care for the injured, but recreation centers can wait until people have time to use them. Schools are immediately needed as emergency shelters. They need to reopen to students as quickly as possible, but not before the emergency response period is over, roads are open for buses, and families are settled. By setting specific return to function goals for buildings and lifeline infrastructure, communities can use their sequence of recovery activities to determine what performance levels need to be built into functional recovery-based design and planning codes. Communities can also assess their existing built environment against the goals to determine where mitigation activities are needed, and which are highest priority.

> FEMA and NIST should lead the development of functional recovery-based design and planning codes from within the re-authorized NEHRP. It should be based on the work of a committee of experts from the Federal Agencies, codes and standards writing organizations, non-government organizations, disaster management professional organizations, and engineering professional organizations such as ASCE and EERI, who will set the appropriate hazard levels and performance goals for all buildings and lifeline infrastructure systems. The work products must be consistent across all elements of the built environment and aligned with the concepts in the *Community Resilient Planning Guide for Buildings and Infrastructure Systems,* published by NIST in May 2016 (NIST 2016). A rating system for easily identifying and publishing the anticipated seismic performance of individual buildings should also be developed and implemented.

NEHRP has and should continue to make Americans safer and our nation more secure, resilient, and financially stronger through research in engineering, earth and behavioral sciences, and public policy. We must also follow through with implementation of the findings through the development of design tools and assistance to States and communities with preparedness and mitigation activities. Thank you for the opportunity to share my views with the Committee regarding the National Earthquake Hazards Reduction Program, and I urge Congress to move quickly to reauthorize, with the outlined improvements, this critical program.

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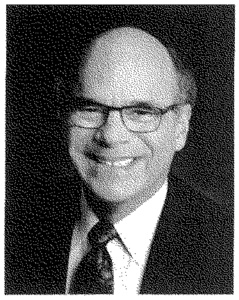

Chris Poland
Consulting Engineer
NIST Community Resilience Fellow
Chairman and CEO, Degenkolb Engineers, retired

Chris Poland is an internationally recognized authority on earthquake engineering and champion of disaster resilience. His passion for vibrant, sustainable, and healthy communities drives his consulting engineering practice. He focuses on community resilience and the buildings and systems that contribute to it. Currently, Chris is a Community Resilience Fellow in the National Institute of Standards and Technology (NIST) and member of the team of authors that are developed and are now implementing a Community Resilience Planning Guide.

Chris is a member of the National Academy of Engineering (2009) and serves on several their study committees and boards. He is a Fellow of the American Council of Engineering Companies, the Structural Engineers Association of California and the American Society of Civil Engineers Structural Engineering Institute. He is also an honorary member of the Earthquake Engineering Research Institute and the Structural Engineers Association of California.

His structural engineering career spans over 42 years and includes hundreds of projects related to the design of new buildings, seismic analysis and strengthening of existing buildings, structural failure analysis, historic preservation, as well as the development of guidelines and standards that are used worldwide. He was a Senior Principal, Chairman and CEO of Degenkolb Engineers during his 40 years with the firm from 1974 through 2014.

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Supplemental

Testimony before the Congress of the United States
House of Representatives
Committee on Science, Space, and Technology

Chris D. Poland, PE, SE, NAE, M.ASCE, F.SEI
Consulting Engineer, NIST Community Resilience Fellow
Member, National Academy of Engineering

On behalf of the
American Society of Civil Engineers

Field Hearing
May 31, 2018
Huntington Beach, California

Supplemental Testimony submitted June 9, 2018

Mr. Rohrabacher and members of the committee. During the question and answer period at the Hearing on May 31, you mentioned that an annual $200M authorization sounded reasonable. The NRC report I cited recommended a $306.5M annual authorization.

During the development of the Senate Bill SB 1768, Senator Feinstein's office requested that we suggest a distribution of the NRC cost estimate to the four Agencies. We submitted our suggestion in April 2017. We have since reviewed our work and revised those suggested authorization levels to the $200M annual amount you mentioned. The resulting recommendations are shown below, and their development summarized on the next page.

I hope this is helpful and will lead to more realistic authorization levels included in the House Bill now under development. I will be pleased to answer any questions you have.

Agency	$300M Annual Authorization	$200M Annual Authorization
USGS	$171.0M	$122.8M
NSF	$ 56.7M	$ 32.2M
NIST	$ 48.05M	$ 25.5M
FEMA	$ 30.75M	$ 19.5M
Total	$306.5M	$200.0M

6/9/2018

Distribution of the NRC $306.5 million annual need

Established by the National Research Council Report "National Earthquake Resilience, Research, Implementation, and Outreach"

NRC report *Earthquake National Resilience* Cost Estimates by Task		Authorization levels per Agency as estimated by EERI for all tasks as reported					All Agency athorization Levels scaled to a $200M total authorization level				
Task	NRC Annual Costs (millions)	USGS	NSF	NIST	FEMA	Total	USGS	NSF	NIST	FEMA	Total
1. Physics of Earthquake Processes	$27.00	$13.50	$13.50			$27.00	$8.00	$8.00			$16.00
2. Advanced National Seismic System – ANSS	$66.80	$66.80				$66.80	$66.80				$66.80
3. Earthquake Early Warning	$20.60	$20.60				$20.60	$20.00				$20.00
4. National Seismic Hazard Model	$50.10	$50.10				$50.10	$18.00				$18.00
5. Operational Earthquake Forecasting	$5.00	$5.00				$5.00	$3.00				$3.00
6. Earthquake Scenarios	$10.00	$10.00				$10.00	$5.00				$5.00
7. Earthquake Risk Assessments and Applications	$5.00	$5.00				$5.00	$2.00				$2.00
8. Post-earthquake Social Science Response and Recovery Research	$2.30		$2.30			$2.30		$2.30			$2.30
9. Post-earthquake Information Management	$1.00			$1.00		$1.00			$1.00		$1.00
10. Socio-economic Research on Hazard Mitigation and Recovery	$3.00		$3.00			$3.00		$3.00			$3.00
11. Observatory Network on Community Resilience and Vulnerability	$2.90		$2.90			$2.90		$2.90			$2.90
12. Physics-based Simulations of Earthquake Damage and Loss	$6.00		$6.00			$6.00		$2.00			$2.00
13. Techniques for Evaluation and Retrofit of Existing Buildings	$22.90		$4.00	$16.00	$2.90	$22.90		$2.00	$6.00	$2.00	$10.00
14. Performance-based Earthquake Engineering for Buildings	$46.70		$20.00	$13.35	$13.35	$46.70		$10.00	$6.00	$6.00	$22.00
15. Guidelines for Earthquake-Resilient Lifelines Systems	$5.00			$2.50	$2.50	$5.00			$2.50	$2.50	$5.00
16. Next Generation Sustainable Materials, Components and Systems	$8.20		$5.00	$3.20		$8.20		$2.00	$1.00		$3.00
17. Knowledge, Tools, and Technology Transfer to/from the Private Sector	$8.40			$4.20	$4.20	$8.40			$2.00	$2.00	$4.00
18. Earthquake Resilient Communities and Regional Demonstration Projects	$15.60			$7.80	$7.80	$15.60			$7.00	$7.00	$14.00
Total	$306.50	$171.00	$56.70	$48.05	$30.75	$306.50	$122.80	$32.20	$25.50	$19.50	$200.00
Percent Reduction in each agency allocation to achieve a 200 million total							72%	57%	53%	63%	65%

Notes

1. The NRC Report referenced in the testimony stipulated the annual cost for each of the 18 tasks, but did not distribute them to the four agencies.
2. EERI compared the numbers in the NRC report to their own 2003 report on the same topic that also called for $300 M per year and stipulated how the funds were to be distributed to the agencies
3. The 2015 distribution of the NRC Annual Costs shown in the second box were sent to Senator Feinstein's office in 2017 for use in the development of the Senate Bill.
4. At the Hearing, Congressman Rohrabacher suggest that an annual authorization of 200 million "sounded reasonable". The third box represents my suggested reductions in the agency authorizations to achieve that level.
5. The reductions are consistent with my testimony in that they maintain full funding for ANSS and Early Warning, generally reduce the other tasks proportionately while not reducing the lowest cost tasks.

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Read 6/9/2018

Mr. ROHRABACHER. Thank you very much, Mr. Poland.

Now, Mr. Arba, you are recognized.

TESTIMONY OF MR. RYAN ARBA, BRANCH CHIEF, EARTHQUAKE AND TSUNAMI PROGRAM, CALIFORNIA GOVERNOR'S OFFICE OF EMERGENCY SERVICES

Mr. ARBA. Thank you, and good afternoon, Committee Members. I am Ryan Arba, the Branch Chief for the California Governor's Office Emergency Services Earthquake and Tsunami Program. Thank you for the opportunity to testify today.

California is vulnerable to a catastrophic disaster within the lifetimes of most residents, and earthquakes is one of those main threats. In fact, California holds 77 percent of the annualized earthquake risk, and that is estimated at over $3 billion a year in risk over a 30-year period. And in more than 70 percent of the states, 40 million people reside within 30 miles of a known damaging fault.

We have kept some statistics of the earthquake impact since 1950 and found that there have been over 200 deaths related to earthquakes, 19,000 injuries, and over $8 billion in Cal OES disaster costs with FEMA, of course.

So CAL OES' responsibility includes leading California's efforts to prepare, mitigate, respond, and recover from earthquakes, but we can't do it alone. The program relies on non-profit, local, state, and Federal partners such as the Federal Emergency Management Agency and the U.S. Geological Survey in order to meet this mission.

Today there are several programs I would like to highlight that are supported in part by the NEHRP to the program administered by FEMA.

The first is the annual ShakeOut event. It is most commonly known as the one-minute drill to practice drop, cover, and hold on, but also includes other opportunities to practice full-scale disaster preparedness exercises and other preparedness activities. It is one of our most leveraged activities. In fact, we have over 10 million residents that are registered to participate in this annual event every year, and the program has expanded to include 52 million participants worldwide. In fact, it has been copied in over 60 countries.

Another thing CAL OES does is we have three seismic catastrophic plans focused on the Cascadia Subduction Zone, which covers the northern three counties of California and goes up through Oregon and Washington. We also have catastrophic earthquake plans for the Bay Area and Southern California.

The work done through NEHRP to develop risk assessments for the state, done by our partners at the U.S. Geological Survey, as well as the California Geological Survey, are supported through NEHRP, and it is that critical component of knowing what the risk is which allows our emergency managers to prepare for that eventual day when the earthquake strikes and we need to respond immediately.

Most recently, the Haywired scenario was released, which was a hypothetical magnitude 7.0 in the Bay Area on the Hayward Fault at approximately 4:20 in the afternoon. The information that is being drawn from this scenario helps emergency managers not only look at the impact to human life and basic infrastructure, but also look at many of our intertwined infrastructure facilities such as utilities, and also takes a look at the impact it would have on Silicon Valley, which not only has a great impact in the Bay Area but also the world.

Finally, California is investing heavily in earthquake early warning, a topic that I have heard mentioned previously today, which can provide seconds to tens of seconds of advanced warning. In particular, the NEHRP program, through FEMA, were funding some research in order to come up with a common tone and alert message so we can ensure that when those earthquake early warning alerts come out, that people are taking the appropriate protective actions to reduce our risk in the state.

So reauthorizing NEHRP is critical to ensure that California and the nation are ready for the next damaging earthquake, and I urge the Committee to consider the following recommendations.

First, reauthorize NEHRP with an emphasis on implementation by state emergency management agencies. One way to increase that would be through state emergency management representation on the NEHRP Advisory Committee on Earthquake Hazard Reduction.

Also, I would urge the Committee to consider expanding the research category known as applied research, which would allow emergency management agencies and social scientists to evaluate the effectiveness of protective action campaigns, for example, and adjust as necessary over time.

So, in conclusion, California is at great risk for a large damaging earthquake likely to impact a large percentage of our population, and NEHRP is a critical component of California's earthquake mitigation strategy.

Thank you again for the opportunity to testify.

[The prepared statement of Mr. Arba follows:]

EDMUND G. BROWN JR.
GOVERNOR

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GOVERNOR'S OFFICE
OF EMERGENCY SERVICES

Ryan Arba
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STATEMENT FOR THE RECORD

Before the United States House of Representatives
Committee on Science, Space, and Technology
Subcommittee on Research and Technology

Earthquake Mitigation: Reauthorizing the National Earthquake Hazards Reduction Program

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Introduction
Chairman Smith, Ranking Member Johnson, and members of the Committee on Science, Space, and Technology. Thank you very much for the opportunity to address the Committee on the National Earthquake Hazards Reduction Program (NEHRP).

With approximately 39 million people, California is the most populous state in the nation. If it were a separate country, it would have the world's fifth largest economy. It has the nation's largest industrial belt, stretching much of the way from Sacramento to San Diego and including global headquarters for computer, movie-television, and digital-entertainment industries. California is also the nation's largest agricultural producer.

California is vulnerable to a catastrophic disaster within the lifetimes of most residents. No community is fully immune. Though wildfires and floods are the most common disasters, earthquakes hold the greatest potential for large-scale destruction. A major disaster would pose significant challenges for restoring people's lives, restarting economic engines, repairing infrastructure, and creating sustainable redevelopment.

The California Governor's Office of Emergency Services is charged with leading the State of California's efforts to prepare, mitigate, respond, and recover from our ever-present earthquake threat. We rely on our federal, state, local, and non-profit partners to execute this mission. The NEHRP is a critical component of this effort.

The NEHRP program comprises of three stages: Research, Development, and Implementation. Through the Federal Emergency Management Agency (FEMA), Cal OES' uses the critical research developed by the National Institute for Standards and Technology (NIST), the National Science Foundation (NSF), and the US Geologic Survey (USGS), to better prepare residents, improve our building codes, and invest in new capabilities such as earthquake early warning to build a resilient California.

This testimony will focus on the earthquake threat to California, Cal OES' efforts to reduce damage that could be caused by earthquakes, and opportunities at the federal level to sustain and improve the NEHRP.

California's Earthquake Threat
Earthquakes are a significant concern for California for several reasons. First, California has a chronic and destructive earthquake history. Since 1950, only 8 percent (12) of federally declared disasters in the state were the result of earthquakes. During this time, however, earthquake disasters have claimed 203 lives and resulted in 18,962 injuries and over $8 billion in Cal OES-administered disaster costs.

There are over 15,000 identified faults in California. Over 200 of these identified faults are considered very dangerous based on their slip rates in recent geological time (the last 10,000 years). More than 70 percent of the State's 40 million people reside within 30 miles of a known fault where strong ground shaking could occur in the next 30 years.

The San Andreas Fault is not the only significant fault/plate boundary in California. The seismicity north of the Cape Mendocino is controlled by faults associated with the Cascadia Subduction Zone, a large fault system offshore that separates the Juan de Fuca Plate to the west and the North American Plate to the east. This area is the most seismically active portion of the state. The Cascadia Subduction Zone is capable of producing great earthquakes (+8 magnitude) and last ruptured in the year 1700, causing what was likely an earthquake in the Magnitude 9 range. The subduction zone is also capable of generating a large tsunami.

Damage due to ground shaking produces significant amount of all building losses in typical earthquakes. Building damage can be both structural and/or non-structural (contents) and both types of damage can cause injury or loss of life. In addition, buildings are also vulnerable to ground displacements associated with primary fault rupture, liquefaction, differential settlement, and landslides. Inundations from tsunamis, seiches, and dam failures can also be major sources of loss to buildings and infrastructure.

Earthquakes large enough to cause moderate damage to structures—those around Magnitude 5.5—occur three to four times a year in California. For example, the Magnitude 6.5 San Simeon Earthquake of December 22, 2003 caused 2 deaths, 47 injuries, and $263 million in damage. The Magnitude 6.5 Humboldt County earthquake on January 9, 2010, resulted in zero deaths, 35 injuries, and $43 million dollars in damage. The Magnitude 7.2 El Mayor Cucapah earthquake (also known as the Sierra El Mayor earthquake) of April 4, 2010 was located in Northern Baja California at the former mouth of the Colorado River. This event shook not only Mexicali and Tijuana but also a large part of Southern California and parts of southwestern Arizona and Nevada. There were two confirmed deaths in Mexicali and 100 persons were injured between Baja California and Imperial County California. The total estimated damage in Southern California from the El Mayor-Cucapah event was $91 million while the total estimated damage between southern California and Baja California was estimated to be $1 billion with most of the damage impacting the agriculture industry and irrigation district in Baja California.

Strong earthquakes of Magnitude 6 to 6.9 strike California on an average of once every two to three years. An earthquake of this size, such as the 1994 Northridge Earthquake (Magnitude 6.7) or the 1983 Coalinga Earthquake (Magnitude 6.5), is capable of causing major damage if the epicenter is near a densely populated area. The Northridge Earthquake caused over $40 billion of disaster losses, 57 deaths, and 11,846 injuries. The 2014 Napa Earthquake (Magnitude 6.0) resulted in over $300 million in damage, 1 death, and over 200 injuries.

Major earthquakes (Magnitude 7 to 7.9) occur in California about once every ten years. Two recent major earthquakes, the 1992 Landers Earthquake (Magnitude 7.3) and the 1999 Hector Mine Earthquake (Magnitude 7.1) caused extensive surface fault rupture but relatively little damage because they occurred in lightly populated areas of the Mojave Desert. In contrast, earthquakes of smaller magnitude but in densely populated areas, such as the 1989 Loma Prieta Earthquake (Magnitude 6.9), have caused extensive damage over large areas.

Based on the most recent earthquake forecast model for California, the USGS and other scientists estimate a 72- percent probability that at least one earthquake of Magnitude 6.7 or greater, capable of causing widespread damage, will strike the San Francisco Bay Area before 2044. For the Los Angeles region, the same model forecasts a 60-percent probability that an earthquake of Magnitude 6.7 or greater will occur before 2044.

Cal OES' Efforts to Reduce Risk
Cal OES invests in reducing risks related to earthquakes throughout the emergency management phases. Cal OES' Earthquake and Tsunami program, which through partnerships with the California Geologic Survey, USGS, the University of Southern California's Southern California Earthquake Center (SCEC), and other universities use advances in earthquake knowledge to help prepare the public for the next seismic event. The most leveraged of these efforts is the annual ShakeOut event, of which over 10 million Californians practice earthquake protective measures known as "drop, cover, and hold on." What began as a one-time earthquake drill has now expanded into a worldwide event. The ShakeOut event registers over 52 million participants in over 60 countries and continues to grow every year.

Though Cal OES works hard to prepare, we know that responding to a large earthquake is inevitable. To meet this need, Cal OES has developed three seismic catastrophic plans. These plans include the Cascadia Catastrophic Earthquake and Tsunami Plan, the Bay Area Catastrophic Earthquake Plan, and the Southern California Catastrophic Earthquake Plan. All of these planning efforts rely on input from the scientific community. Specifically, the third California Earthquake Rupture Forecast (UCERF3) helps emergency managers understand the specific threat to each region and allow planners to determine the best way to move equipment and commodities to support disaster survivors.

Scientific studies on earthquake scenarios help create the impetus for local agencies to bolster their preparedness efforts. The Haywired scenario, developed by the USGS' Science Application for Risk Reduction and supported by a coalition of agencies including Cal OES, highlights the impact of a hypothetical Magnitude 7.0 earthquake occurring at 4:18 pm on the Hayward fault in the San Francisco Bay Area. The impact would be severe; estimates include 800 fatalities, 18,000 injured, 22,000 trapped in a stalled elevator, 2,500 trapped in severely damaged buildings requiring search and rescue, and as many as 80,000 single family dwelling fires occurring near the epicenter. The Haywired scenario expands to impacts beyond the initial response, detailing how utilities, critical infrastructure, and technology firms in Silicon Valley could be compromised for extended periods of time.

Earthquakes are not the only seismic event which threatens California. Near and distant shore tsunamis as well as California's seven high-risk volcanos provide a constant reminder that seismic threats are ever present. A large Cascadia Subduction Zone Magnitude 9.0 earthquake could cause untold damage to the northwestern part of California; in addition, the tsunami following within the hour could bring 20 feet of inundation to coastal communities further exacerbating the problem. The tsunami threat does not need to begin with an earthquake in California. In fact, estimates of a Magnitude 9.2 earthquake in the Alaskan Aleutian Islands could cause wave heights of up to 30 feet in some parts of California and cause damage along all of California's coastline. Damage from a volcanic event could have impacts beyond the initial communities, with agriculture and transportation compromised. While many may believe that a volcanic event is unlikely, California volcanologists would disagree. Recent estimates state that the likelihood of a volcano eruption occurring in the next 30 years is 26%, which is the same as a Magnitude 6.7 or higher earthquake occurring on the San Andreas fault. Cal OES works with its scientific partners to further understand these additional seismic risks and plans for their consequences.

Earthquake Early Warning
Further, advances in scientific understanding of earthquakes and technological developments have resulted in the capacity to rapidly analyze earthquakes and provide products that are vital to emergency management and public safety. One such advancement is the capability to provide early warning of an earthquake a few to several seconds prior to the actual arrival of destructive ground motions from a large and damaging seismic event.

The seconds or minutes of advance warning can provide people with an opportunity to take actions like "Drop, Cover, and Hold On" to protect life and property from destructive shaking. An earthquake early warning system can give enough time to slow and stop trains and taxiing planes, to prevent cars from entering bridges and tunnels, to move away from dangerous machines or chemicals in work environments and to take cover under a desk, or to automatically shut down and isolate industrial systems.

Taking such actions before shaking starts can reduce damage and casualties during an earthquake. It can also prevent cascading failures in the aftermath of an event. For example, isolating utilities before shaking starts can reduce the number of fire initiations. This effort aligns with California's goals and objectives to protect lives and property.

The 2016-17 State of California budget passed by the Legislature and signed by the Governor, included $10 million dollars in funding. The funding supported the installation of 183 new seismic sensors and 4 permanent positions to perform research on necessary technology and other technical aspects which will integrate public and private infrastructure, provide public education, and conduct education and training. Then in September 2016, Senate Bill 438 (Hill, 2016) was signed into law to further advance the development of the early warning system by establishing a governance structure to coordinate and direct activities related to the establishment of a CEEWS. The implementation of the California Earthquake Early Warning Program (CEEWP) establishes Cal OES as the lead for implementing CEEWS and ensuring its continued long-term success.

Cal OES released its earthquake early warning business plan on May 2, 2018, as required by CA Senate Bill 438 (Hill, 2016). The plan outlines five components: 1) detailed costs of the system and program, 2) identification of funding sources, 3) expected roles and responsibilities among sectors and organizations, 4) roll out schedule for public alerting, and 5) risk analysis. The business plan will shape the path forward with our partnering federal and academic institutions to further our shared goals.

NEHRP Essential to Continued Mitigation Efforts
NEHRP continues to be a critical program advancing Cal OES' earthquake preparedness and hazard mitigation objectives. In the past, Cal OES invested funding through the NEHRP program to achieve the following outcomes:

Increase statewide earthquake preparedness: With support from the Southern California

Earthquake Center at the University of Southern California, Cal OES hosts regional preparedness and hazard mitigation workshops, sector specific virtual workshops, and other meetings all leading to the annual ShakeOut event. Last year the event included over 10 million participants in schools, businesses, and other organizations, and inspires individuals and families to prepare for a large, disruptive earthquake.

Increase business resilience: Cal OES supports several QuakeSmart workshops, designed to help meet the specific preparedness needs for business owners.
Support social science research for earthquake early warning: Cal OES works with researchers from California State University Fullerton to conduct literature reviews, and conduct studies to determine the appropriate alert tones, phrases, and images to ensure successful adoption of protective measures.

Recommendations for NEHRP
Cal OES urges Congress to reauthorize the National Earthquake Hazard Reduction Program with an additional emphasis on implementation by state emergency management agencies.

In addition to generally reauthorizing NEHRP, Cal OES encourages FEMA to lower or eliminate the 50% match requirement for the NEHRP Direct State Assistance Program funding to enable State Earthquake Program Managers to successfully accomplish the intent of NEHRP. The State Assistance Program provides grant funds to States for core earthquake activities vital to the success of State programs. Without the funding of State Earthquake Programs, States' capability to protect lives and property could diminish. Due to the high match requirements, many states do not participate in this program.

In additional to renewing or restoring funding, it is important to increase emergency management representation on the NEHRP Advisory Committee on Earthquake Hazard Reduction (ACEHR). The Advisory Committee assesses "trends and developments in the science and engineering of earthquake hazards reduction; the effectiveness of NEHRP in performing its statutory activities; any need to revise NEHRP; and the management, coordination, implementation, and activities of NEHRP." All of these efforts intertwine with emergency management and would benefit from increased participation.

Cal OES also encourages NEHRP to expand the research categories authorized to include "applied research." This form of research is defined as the "aspect of scientific study where knowledge is tested to ensure its applicability to practical problems." In essence, Cal OES and partnering organizations could leverage additional research in this area to study the effectiveness of protective action campaigns, and adjust if necessary.

Conclusion
California is faced with a great risk for a large scale, damaging earthquake that is likely to affect a large percentage of its residents due to populations being located on top of many active faults. NEHRP is an essential component of California's earthquake mitigation strategy and allows the state to have a much broader footprint and touch, including partnerships.

Thank you for the opportunity to testify before you today.

Ryan Arba Biography

Ryan Arba serves as the Branch Chief for the California Governor's Office of Emergency Services, Earthquake and Tsunami Program. His program covers a wide swath of seismic hazard preparedness, response, and mitigation. Most recently the Earthquake and Tsunami Program expanded to include the California Earthquake Early Warning Program. This program will be the first state in the nation to implement the earthquake early warning capability, and thus further California's resilience to seismic hazards.

Prior to his appointment Ryan served as the Deputy Regional Administrator in the Coastal Region, filling various roles through the federally declared 2014 South Napa Earthquake and 2015 Valley Fire. Ryan holds a Master's of Public Administration from the University of Southern California.

Mr. ROHRABACHER. Thank you very much for your testimony, and thank you for the testimony of all of our witnesses.

I will assume the first responsibility of having five minutes to ask you some questions and have a little dialogue here.

Mr. MCNERNEY. Mr. Chairman, may I ask a question first?

Mr. ROHRABACHER. Yes.

Mr. MCNERNEY. Are we expecting more than one round of questions?

Mr. ROHRABACHER. You know what? If we have time, we will do exactly that. We do have to be out of here at four o'clock? So we have an hour, and we will use that time, if you so choose.

It is my time, but my time is running out now.

[Laughter.]

Mr. ROHRABACHER. Listen, I want to get a little better understanding on the record here of the type of threat, of the magnitude of the threat that ordinary people in our area and our state are facing.

I noted that the statistics were that if there is a 6.7 earthquake, there is a 99 percent chance of having one of these in the next 30 years. What is a 6.7 earthquake? When San Francisco was leveled, what magnitude earthquake was that, et cetera? Does anyone want to tell me? Go ahead.

Dr. HICKMAN. I will start with that. So, the 6.7 earthquake is the equivalent magnitude to the Northridge earthquake which occurred in the L.A. Basin in 1994 and caused a great deal of damage, tens of billions of dollars of damage. The reason that the 6.7 threshold is used is because that represents the kind of damage done by a Northridge-type earthquake, either in the L.A. Basin or in San Francisco.

Mr. ROHRABACHER. All right. And what about it says also that we have almost a 50/50 chance to have a 7.5 earthquake. How much greater is 7.5 than 6.7?

Dr. HICKMAN. It is a lot greater, of course. It is greater in terms of ground motions and damage, and also in terms of extent, because a large earthquake like that essentially unzips a longer piece of the fault. So the more fault you unzip, essentially, in an earthquake, the more area is impacted.

Mr. ROHRABACHER. Let me ask you something specific on that. We know that there was some freeway damage when we had the Northridge earthquake. I remember that very well. But for a 7.5 earthquake, which is a 50/50 chance, or so we have been told, would the freeways remain operative? Would our water systems remain operative? Would our airports remain operative? And how about the electric system? Would those fundamentals for our society to function, would they be taken out of service by this?

Dr. HICKMAN. It may be a question for someone else on the panel?

Mr. ROHRABACHER. Mr. Poland has an answer to that. Go right ahead.

Mr. POLAND. Let me speak generally about that. A magnitude 6.7 earthquake, like the Northridge earthquake, causes a significant amount of damage. It will not cause a lot of building collapses, even with the most vulnerable kinds of construction that we have. It causes a considerable amount of disruption depending on the area that it is in. A community may be able to recover fairly well depending on if they have all the resources that they need.

Mr. ROHRABACHER. What about the 7.5?

Mr. POLAND. The 7.5 earthquake is a different animal. It is extremely large. It is at the level that we are designing buildings and transportation systems for. It is not the largest that we expect, but it is at the level that we are designing for. Right now, our building codes are basically designing the buildings and systems to be safe. That means that people are going to be able to be safe if they are inside and get out and be out until the buildings are repaired.

Now, that takes care of the buildings that have been built since about 1980 or 1985. Buildings that were built before 1980 or 1985, about 50 percent of them are not going to be usable. They are probably going to need to be replaced. Ten to 15 percent are going to collapse and kill people. This is at magnitude 7.5. All the research that we do and all the work that we do helps us understand how to fix that problem, but the problem sits with the existing buildings and infrastructure systems, and money is needed to rebuild those things.

Mr. ROHRABACHER. Let me go down the list. Will the freeways stay up?

Mr. POLAND. The freeways in California will likely stay up because since 1971 we have been working on our freeways.

Mr. ROHRABACHER. Okay. What about the electric system?

Mr. POLAND. Depending on the electric provider, the electric providers have been working on that. I can't speak expertly about that.

Mr. ROHRABACHER. What about water systems?

Mr. POLAND. Water systems are highly vulnerable because they are dispersed across a large area. They cross liquefaction areas, they cross fault zones, they cross landslide zones, and all those things have really not been taken into account in the design.

Mr. ROHRABACHER. We get the message. How about the airports?

Airports, it depends on where they are. It depends on whether they are sitting on landfill and they are going to be subject to liquefaction or not.

Mr. ROHRABACHER. All right. Well, a 7.5, that is 50/50. The next 30 years we have a 50/50 chance of that magnitude of an earthquake. What is the possibility that we might have something even more damaging than that, even greater than that?

Mr. POLAND. The way structural engineers talk about this—and this is one of the issues we have about getting everybody to collaborate, because we need to talk the same language. The community resilience work will give us that. But structural engineers design their buildings with basically a 500-year return earthquake, return event, and a 2,500-year event is the larger event that we are expecting, and it can be up to 50 percent stronger. As was said here, it covers a larger area.

Mr. ROHRABACHER. Am I taking too much time? Yes, we will have another round.

[Laughter.]

Mr. ROHRABACHER. Mr. Takano?

Mr. TAKANO. Thank you, Mr. Chairman.

I want to spend a little time on building codes.

Mr. Poland and Dr. McCabe, the National Institute of Building Sciences recently released its 2017 interim report which found that for every $1 spent on hazard mitigation, the nation saves $6 in disaster costs. What impact should this report's finding have on earthquake mitigation investments?

Dr. MCCABE. I think the answer is that NEHRP needs to be reauthorized, very clearly, and that we need to continue the work. Having buildings and infrastructure that perform well and don't require significant clean-up and rebuilding is central to keeping people in their homes, keeping the economy functioning, and minimizing disruption. The earlier study by NIBS, the number was about $4. So the numbers are self-explanatory. Investing in mitigation pays off. If you invest in improving your building performance for an earthquake if you are in areas where high winds may be expected, it will likely do better with that. A water system that is improved in terms of its earthquake performance likely will be more reliable just in normal service.

So the investments pay off over time, and in an area in Washington, DC. where there are significant issues with the water supply, as in other areas of the country where there are older systems, these newer systems perform substantially better. So investing is an important tactic in keeping the economic health of the country and to avoid having significant disruptions that cause resilience problems.

Mr. TAKANO. Thank you so much for that answer. And we are talking specifically about building codes.

Dr. MCCABE. Yes.

Mr. TAKANO. We are talking about examining building codes going forward —

Dr. MCCABE. Yes.

Mr. TAKANO.—so that all future construction conforms to adequate building codes. And to look at retrofitting existing buildings, or rebuilding them completely.

Dr. MCCABE. Yes.

Mr. TAKANO. Mr. Poland, do you want to respond?

Mr. POLAND. I would like to add to what Dr. McCabe said with regard to existing buildings. We don't need all of the buildings in the built environment to be able to be used immediately after an earthquake. It is not necessary. There are certain types of buildings that we need within a few hours—hospitals, police stations. Those sorts of things have to be available to manage the response and take care of the injured.

Another set of buildings where people live in their neighborhoods, those need to come back to life, but we have two or three weeks to get that to happen. We have time to do some repair work. The basic economic engine of a community and its business environment and all of that, there is more time available to do that. We have to get the workforce taken care of first.

The reason I say that is because when we look into the existing building environment, we can design and retrofit those buildings to different levels, and this is what performance-based engineering allows us to do. This is what setting the performance goals that the community resilience guide from this talks about. When we go about doing that, the new generation of code will recognize what needs to be done so our communities can take the resources that they have and apply them to the areas that are most needed as they plan their recovery process.

Mr. TAKANO. I get what you are saying about sort of triaging —

Mr. POLAND. Yes.

Mr. TAKANO.—prioritizing what buildings we must make sure are resilient. What about multi-family or dense residential buildings? I understand that in many parts of California there is a social justice concern about poorer people, lower-income people occupying buildings that may be less earthquake resilient. What thoughts do you have, either of you, on this topic?

Mr. POLAND. Well, let me just say first, and then anybody can talk about that, in my mind the key issue is to be able to maintain your workforce. This is something that was very important in San Francisco as I worked on their program. You need people to stay in the city, to be able to get back in their homes and get back to their life so they can go back to work. If they don't, they leave. And if they go someplace else, you can't restore your economy. So that is the key aspect.

Now, when you go to recognizing where the key vulnerabilities are, you are going to find that the folks that are economically disadvantaged, the folks that you are talking about, are the ones that are living in the most dangerous buildings, and they have the least ability to help pay for that. So the issue is how do we make sure—and we need those people for the workforce. How do we make sure that the retrofit work can be done and be paid for? Because as part of the community obligation to protect their workforce, that has to be taken care of.

Mr. TAKANO. My time is running out. It has elapsed, the Chairman has kindly showed me.

[Laughter.]

Mr. TAKANO. I have no time to explore this further, so I will yield to my colleague, yield back to the Chairman.

Mr. ROHRABACHER. Thank you.

Mr. McNerney?

Mr. MCNERNEY. I thank the Chairman, and I thank the panel. I think your testimony has been very informative so far.

As we have seen with recent natural hazards, it is clearly imperative for lifelines such as utility lines, water systems, transportation systems, to withstand hazards and to be back online as soon as possible, and that strong standards are a very important part of making sure that that is the case.

So my question is this for Mr. Poland, if you can answer it: Are there any codes that apply to underground water conveyance tunnels?

Mr. POLAND. When you think about codes, most of us often think about building codes. It is a building department. It is a set of rules that you have to go by to get your permit. When you go to the infrastructure systems and water systems, there is no building department. There are various agencies that regulate the design and construction, but most of the time water infrastructure providers set their own standards for what they are going to design to be based on what they perceive is necessary for their community, what they believe they can afford to do within the rate structures that they have to live with, and what their community is saying is important to them.

What we have learned—and this is published—is that our infrastructure systems are designed to a very uneven level of performance and safety. In fact, they are mostly designed for day-to-day operations, for normal conditions, with very little regard to the high-consequence, low-probability events like earthquakes.

Mr. MCNERNEY. Well, what I hear you saying is that there really aren't any codes, standard codes really, that are used in those.

Mr. POLAND. Correct.

Mr. MCNERNEY. So would it be safe to say that the large water conveyance tunnel plan, the Governor's plan, is not resting on sound geoscience to prevent significant risk?

Mr. POLAND. No, I wouldn't say that. One of the nice things is, I believe, when you have a project like that, the kind of effort that goes into it in recognition of what the hazards are, that special studies are done, and I assume that these have been done and that the protection is going to be in place. I would not draw that conclusion from what I just said.

Most water districts in communities are small. They serve a small area. They are localized, and they are subject to the kind of discussion that I just made.

Mr. MCNERNEY. Thank you. That is a question that is very important to me in my district, how safe are those plans, and recent studies I have heard and testimony that was taking place in San Joaquin County showed that there wasn't a set of standards that would be reliable in terms of designing large tunnels for big advanced projects that cross a large region of space.

Mr. POLAND. And I don't want to disagree with that. I don't want you to interpret my comments as disagreeing. Those standards are particular to that particular type of construction. I am not familiar with those at all. But I would like to believe that because of the dependence on that water by people downstream, by people in Southern California and the Central Valley, that we are not going to be able to overlook the consequences of a major earthquake. That has to be built into the system.

Mr. MCNERNEY. Thank you.

The USGS produces and updates, Mr. Poland, national seismic hazard maps. How would developing community seismic standard maps help communities across the nation prepare for earthquake risk?

Mr. POLAND. What we have now from USGS, which is extremely helpful, is an ability for every location within a city to determine what the strong motion is, and they can produce maps for us that show us the contours across a city. That is great for the shaking level, how hard it shakes.

We don't have those kinds of maps universally for areas that are subject to liquefaction, and when you talk about utility systems, and your utility system is brought out across your whole community, you have to know where your liquefaction is going to occur if you want to understand what is going to happen to your utility systems.

The same thing with faulting and landsliding. There are targeted areas, very dense urban areas where some of this information is available, but it really needs to be available for any community that wants to understand their resilience.

Mr. MCNERNEY. Has my time expired? Oh, another minute? Oh, boy, I am going to use it.

Mr. Poland, you mentioned that there is chronic underfunding of developing standards and for the United States. How do we compare, in terms of having standards, to other countries around the world? I mean, are we behind? Are we ahead? Are we in the middle of the pack? How do we stand?

Mr. POLAND. It depends on which areas. In Third World countries, they don't have any standards. In countries comparable to ours, there are a wide variety of standards. I have never done a study myself to compare those. I know there are international forums where we get together and we talk about each other's standards.

I think the most important part is it is not how we compare to our neighbors. It really depends on how is our built environment going to perform, and is it going to meet our expectations or is it going to surprise us and we are going to be caught with a built environment that is not going to serve us very well?

Mr. MCNERNEY. Thank you, Mr. Chairman. I will yield back.

Mr. ROHRABACHER. How do we compare in terms of the danger that we face as compared to other countries? I mean, I remember reading accounts of St. Sebastian in Spain, that they had a huge earthquake there. Is Europe still—where do they compare to us? Where do we compare to other countries? Japan seems to be going through a number of earthquakes. So the risk to our country compared to other countries, where would you put it?

Dr. MCCABE. It depends on where you are. If you are along the Ring of Fire, Japan and New Zealand in particular have significant risk, all the way up the West Coast of the Americas. That is all part of that Pacific plate juncture. Interestingly, in Chile, their building codes are based on U.S. building codes in large part, and they have had significant strong shaking down there, and their buildings have done quite well. The latest one was in 2010. So we have anecdotal information from actual application of our building codes, but it is a significant risk.

Mr. ROHRABACHER. So this Ring of Fire that we are talking about, does that mean that all the countries that are around that edge of the Pacific are at the maximum risk in the world of having quakes?

Dr. MCCABE. I will defer to my seismology colleague here.

Dr. HICKMAN. The Ring of Fire countries obviously have a lot of risk.

Mr. ROHRABACHER. You have to talk into your mic, please.

Dr. HICKMAN. The Ring of Fire countries obviously have a lot of risk, and we share information with those countries. For example, we learn about how to model or understand reductions in earthquake damage by looking at Chile or Japan. However, if you look at other countries, like India, for example, and also Iran and Iraq, Italy, they face a great deal of hazard from smaller costs, not as dramatic as the Ring of Fire.

But at the end of the day, a lot of countries suffer because their building codes are not as good as ours, and their enforcement of their building codes, if they have them, are not as good as ours, and that was mentioned earlier. The same earthquake that makes for good building codes like ours will do a lot less damage than in countries without those building codes. So the risk is spread around the country.

Mr. ROHRABACHER. I understand. That is a good point, and it has been made today, and we hear that. We really need to make sure that—you can't stop the earthquake, but we can be prepared for it. Thank you. I am a Boy Scout. "Be Prepared" is the motto of the Boy Scouts, right?

But let me ask you this. In terms of actually understanding the threat, I would like to ask you a little bit about prediction and warnings. Does it make sense for us to have sensors in space, satellite sensors? For example, this Committee oversees that type of activity, sensors that might be able to determine pressure building or smaller movements of the earth. Does it make sense for us to be doing that?

Dr. HICKMAN. Monitoring from space does play an extremely important role in keeping track of the deformation of the earth; for example, radar images taken from satellites. That is very important for mapping out hazards, where the faults are being loaded most rapidly when an earthquake occurs, how does the crust respond. But we really cannot do short-term prediction from this. We can't do short-term prediction at all. We thought it was easier before. And by "short-term" I mean predicting that there is going to be an earthquake of a particular size in a particular place tomorrow or the week after.

We used to be more optimistic about that. We now know that earthquakes are much more complicated than that. Earthquakes basically start small. Some of them decide to grow big, but most of them stay small. The ones that become big, they start very deep. So it is very hard to see the signals associated with the initiation of an earthquake close enough to tell whether you could even predict an earthquake at all at that level.

Mr. ROHRABACHER. We end up predicting an earthquake to say within the next five days there will be an earthquake, so they come back on the 6th day, and then you have the earthquake on the 10th day. I think we are facing that kind of thing. So what our efforts should be, instead of providing warning, we should focus on what comes next to make sure that, number one, beforehand we are prepared; number two, what do we do after the earthquake has come to mitigate that.

Dr. HICKMAN. This is exactly where early warning comes in. Early warning is not early warning for the earthquake. It is early warning of shaking from an earthquake that has already started. So once the earthquake starts, you don't have to predict it anymore. You just need to have sensors very close to the starting point. If you can pick that vibration up, you can see how big the earthquake was, how much shaking there is going to be, and you broadcast that out as fast as you can.

The emphasis is shifting, of course, away from earthquake prediction, because that is not going to save lives and property. But warning about shaking from an earthquake that already has started will, as well as increasing the strength of the built environment.

Mr. ROHRABACHER. All right. My time is up again.

Mr. Takano?

Mr. TAKANO. Well, Mr. Chairman, I am confident we are going to get through all these questions because we are taking turns and playing nice.

Mr. Poland, I just want to continue my question where I left off with what you were saying. It was interesting to me what you were saying, that we have to focus in the aftermath of a major earthquake on preserving our workforce because that is going to be key to rebuilding, and a large part of our workforce is going to be coming from the lower-income folks who are going to do the rebuilding, and a lot of these low-income people live in our most vulnerable areas.

I recall from this latest earthquake in Mexico City that we saw the tall buildings actually did okay, but it was these mid-size buildings that didn't do so well. Can you maybe describe what the risks are in these low-income areas and maybe paint that picture more fully for us?

Mr. POLAND. I think the experience that we saw in Mexico City had more to do with the time that the buildings were built and the quality of the construction that went into building the buildings. It didn't really have as much to do with the height or not, so just to say that.

We do know that there are classes of buildings that are extremely vulnerable, unreinforced masonry buildings, the wood-frame buildings with soffer stories. We call them the soffer story buildings. There is an opening at the bottom, so there is a real weakness down there, and the older concrete buildings that don't have sheer walls.

When you walked into this building, you probably noticed the diagonal braces on this building. Those braces were put in there to supplement the strength of this building because it was an older concrete building that didn't have enough strength to be able to resist the lateral loads. So they put braces in to hold the building up so it would be able to perform. That is good.

The point that I want to make is that the older buildings that we have, because they are older, don't have the features, don't have the same quality, and so they tend to be the ones that tend to be more affordable for folks to be able to live in, and those are the buildings that are the most vulnerable buildings.

Now, in order to correct that, and where the NEHRP program comes in, is there is a huge amount of research and activity that needs to go into understanding about just how much we need to fix the buildings. An engineer given a task will solve it. I might spend three times as much money as I need to, but I am not sure because I don't have all the information that I need. So we do the research, we figure out the programs, we do the testing, and I can identify through analysis what actually needs to be done. The less I have to spend on each building, when a community looks at this, the more buildings we can fix.

Mr. TAKANO. Mr. Poland, so we don't want to over-spend, right? I wish we had an economist who was also here with us, because part of this problem we have, this conundrum, is the cost of retrofitting, or the cost of just rebuilding if we think that retrofitting is not enough.

Was it you, Dr. McCabe, who was talking about a block by block analysis, or was that somebody else? You were talking about block by block, right? That seems awfully tedious, but is that something that we can do, and is that something that is worth the money? Tell me more about that.

Mr. POLAND. Well, I think it is worth the money. We can't go block by block and do the kind of detailed evaluation by the design professionals that I am accustomed to doing for my projects. You are right, that is way too much. But let's start with the ground shaking and liquefaction potential.

As the science develops and the understanding of what is going on underneath the ground—I am talking like a structural engineer now, what is going on down there, what the vulnerabilities are—that information can be extrapolated, and we can get much better information block by block if the science is improved so that we can understand. USGS needs to do the research to sort that out.

As NIST and Steve McCabe's group does their research and looks at building performance, we can recognize classes of buildings. Right now we categorize 15 different classes of buildings, and our procedures are all built around those things. As we understand how those buildings perform, then all we have to do is identify in a community what class that building is, and it gives us a good measure about how it is going to perform, so then we can understand where the mitigation needs to be done.

So over on the science and research development side providing new information to allow us to extrapolate to our inventories of buildings so that we can officially figure out what needs to be done.

Mr. TAKANO. Do you have any idea whether the current compromise in the Senate legislation is including resources for this kind of research or not? How much more would it cost us to do this?

Mr. POLAND. The National Research Council in 2011, at the request of NIST, did a study about what we needed to spend in the NEHRP program over a 20-year period. I mentioned this in my testimony. They came back and said we need to spend $306 million a year for 20 years, and they gave us 18 different line items of things we needed to do and a whole book full of explanation about what needed to be done in order to achieve what I am talking about.

So my answer to you is we need $300 million. I believe the Senate version has $80 million in it, or $90 million.

Mr. TAKANO. My time is up. It is not just by coincidence that we are talking about increased need for money. The Chairman, I just put that in front of him. It just happened to be at the same time.

I yield back.

Mr. ROHRABACHER. Mr. McNerney.

Mr. MCNERNEY. I thank the Chairman again.

I am going to follow up on your question.

Mr. Poland, on the block by block analysis, wouldn't it tend to be, getting in its own way—I mean, if there is so much data, if there was a big hazard, wouldn't that kind of information be just so massive and so inaccessible that it wouldn't be useful; in fact, maybe even cause problems? Do you envision something like that as well?

Mr. POLAND. No, I don't. Let me give you an example. In San Francisco—you probably heard about this—they put in place a program to retrofit their soffer story buildings. The recommendation was made, because San Francisco is bound on three sides by water, that if they didn't do something to keep their people in town, to shelter in place, if you will, that they would leave, and they would never get them back. The recommendation was that 95 percent of the people need to shelter in place.

They came back and did some studies and found out that we were at about 50 percent, and we needed to get to 95 percent. We could get 25 percent more people sheltering in place if we strengthened the soffer story buildings. So that program was put in place.

Now, as we started to work through the details of was it really going to accomplish what it needed to accomplish, it became really important to understand how the shaking was going to vary across the city, where the liquefaction was going to occur, where there was landslides, because a building in a landslide area, there is really not much we can do to it economically to make it shelter-in-place capable. If it is in a liquefaction area, it is the same thing.

So having the block by block information to answer a specific question—how many of those 6,500 buildings are in areas that we can't fix, how many can we fix—is what I am talking about that we need the information block by block.

Mr. MCNERNEY. All right. Thank you.

Dr. McCabe, you mentioned that you want to prevent a building from collapsing, an important part of the standard, but also a building having survivability so that it can be reoccupied and reused quickly. Where are we with regard to those kinds of standards that allow a building to be reused after an event?

Dr. MCCABE. Well, with an existing building that has been built to an older standard, a 1950s-era standard, the level of performance is going to be less than a newer building, right? It is a function of the age of the building, the type of the building, the level of the shaking certainly, the ground that it is on. A new building properly designed and competently done is going to probably do pretty well, except under great earthquake-level shaking.

Mr. MCNERNEY. So, for example, that new building they are putting up in San Francisco, it is taller than anything else by quite a bit, you would think that would be not only survivable but would survive intact and allow people to use it the next day?

Dr. MCCABE. I wouldn't say that.

Mr. MCNERNEY. Well, the next day is a little bit —

Dr. MCCABE. Yes. I mean, what the conversation is evolving to is not necessarily a life safety, get out of the building, pat yourself on the back, and you may have to demolish the building question, which is what it was maybe when NEHRP was enacted. We have gotten things refined. We have gotten things improved. The ground motion information, the hazard modeling is improved. We have done a significant improvement in our ability to design new buildings.

What we are doing, though, is we are evolving the conversation. Chris Poland is talking about shelter in place, keeping people in their communities, keeping the communities able to continue to function. That is an essential part of this whole conversation. We have met an initial goal here, and we are moving beyond that, and we have done this on our own because it is an important thing to do. We want to keep communities viable. We may not be able to get a building reoccupied immediately, a hospital, a fire station, something like that certainly. There may be more time required. But as we get better, we ought to be able to shorten those times as well. That is where this immediate occupancy or the functional recovery standard that is being talked about in California comes in.

Mr. MCNERNEY. So what I am hearing is pointing to a vision where all these agencies working together can make a community livable after an event.

Dr. MCCABE. Yes. We are stepping the game up, and it is due to the conversations about resilience, about knowing the ground motion hazards better, about recognizing that buildings are not stovepipes by themselves but they are connected via lifelines—electrical, water, waste water. All of these things are necessary to keep a community alive. So we have a broader vision now, which is pretty exciting.

Mr. MCNERNEY. Okay. I yield back, Mr. Chairman.

Mr. ROHRABACHER. All right. We have time for one more round, if the witnesses have time for one more round for us.

Let me just note that I think one of the primary responsibilities of government, especially the Federal Government in this case, is to make sure that we are prepared for major threats to the overall safety and well-being of the country and the American people, and that includes what we are discussing today, and thank you for your input on that, and that is understanding what threat we face and how should we approach that threat about earthquakes.

There is also a threat that I am very concerned with about asteroids, that an asteroid could appear. No scientist ever told me that, oh, no, that will never happen, or it is a thousand years away. Not one scientist I have ever talked to would be surprised if we didn't find one five years away tomorrow.

We have people who are warning us about our antibiotics that are being faced with new challenges at the bacterial level.

We have EMP, which is some solar activity that could happen and fry our electric system.

All of these are challenges that I think are important for the Federal Government to, number one, look at and see how much danger there is and try to at least see what we can do, if nothing else, to mitigate the damage that will be done if we can't stop it altogether. I am hoping that we would develop a system that could actually take an asteroid and nudge it off of a path far enough out so that it wouldn't hit the earth. But then again, we have to know that that might not happen.

With that said, I want to thank all of you for giving us some suggestions today. But it comes down to, in all of these areas, how much money are you going to spend. Mr. Poland was very clear in his testimony: We have to spend more money. Okay. Let me just note that we are spending already a trillion dollars a year more than we are taking in, already. That is without doing these things, without coming to grips in a big way.

So what we have when we discuss these issues of the safety of large chunks of our population, we have to understand that if we are serious about that, we have to figure out where the money will come from and what programs will have priority. Does this have priority over other types of programs? I mean, we just voted for a farm program. I voted against it, but I don't know what my colleagues did. We had an amendment that said we are going to spend so many millions of dollars promoting beer and wine, America's beer and wine.

Now, when you are spending more than a trillion dollars a year more than you are taking in, that just means we are going to have to start making priorities in terms of what we are going to spend, and I assume by your testimony today is what you are telling us is that there is a serious threat. That is why I came along in the beginning saying how serious is this threat? There is a serious threat that large numbers of people in our population could be in great danger, and if we focus on this it will cost a certain amount of money, but we can save lives afterward.

With that said, I would hope that the next time—I am not going to ask you guys or any of our witnesses to say what areas we should cut. But let me just suggest that that bit of information as comparing one program to another will help us a lot more than simply telling us what the threat is.

Does anyone have any suggestion of how much money we need to spend now? Mr. Poland suggested $400 million. I forget the exact amount.

Mr. POLAND. It was $300 million a year.

Mr. ROHRABACHER. Two hundred million dollars a year.

Mr. POLAND. Three hundred million.

Mr. ROHRABACHER. Three hundred million dollars a year. And is there some other program that you think, a science-based program that you think does not measure up to that?

Mr. POLAND. Great question. You are in a whole lot better place to judge that than I am because you see all the programs. We are the experts. We see a program. We recognize that there are things that could be done that are not being done.

I know in my practice, for all the thousands of buildings that my staff and I have evaluated and recommended strengthening for, very few, probably less than 20, were ever strengthened because it is too expensive. Why is it too expensive? Well, we don't know everything we could know.

Now, if you could invest $300 million a year in the program, and you could create design guides and maps and GIS systems and tools that are necessary to activate the money that is available out there to do all this, none of this money is going for brick and mortar, none of it is going to fix anything. All it is doing is doing the research necessary to provide the refined tools to make this thing affordable and practical so that people go ahead and want to do it.

And the other thing that I keep noticing is when these hazards occur, when these natural disasters occur and people haven't taken care of things because they didn't think they could afford it and they don't have insurance, then you guys are great. You come in—and I hope you do it for us when it happens to my community—you come in with a whole lot of money and you fix things, and that is great, and that is part of what this program is about, trying to figure out how to get the cost of that repair bill down, because the Federal Government is the last stop for repairing things.

So it seems to me the comparison you are asking for, the programs to cut, I have no idea.

Mr. ROHRABACHER. Okay.

Mr. POLAND. But I think that we need to have a different view of what this $300 million a year is going to get us.

Mr. ROHRABACHER. Well, we do have, just as I say, lurking right there in the background as we are trying to make our decisions, a trillion dollars in debt every year more. So at some point that will be a huge threat to the well-being, and I hope we never see it, the type of financial crisis we are setting ourselves up for by not being able to prioritize.

But with that said, you have made your case today, I think very well.

Yes, sir, Dr. Hickman.

Dr. HICKMAN. I think those are great questions. We obviously are not in the same position you are. But I look at the Haywired scenario, which is the scenario of the losses from a magnitude 7 earthquake on the Hayward Fault, more than $82 billion in damage, 18,000 injuries, 800 fatalities, and then there is fire after that, loss of water, loss of telecommunications, migration of people out of the Bay Area, the potential devastation of an economy.

There are some tough decisions to make, but I think we need to revitalize the entire NEHRP program. This is a huge problem, and I agree with sheltering in place. We need to look at infrastructure, we need to make sure the water comes in, the roads can come in for rescue personnel, the water can come in to fight fires.

Mr. ROHRABACHER. And strengthening them, as you have made the point, actually can make them more effective even before any type of earthquake were to happen.

Just one last question about the threat itself. We see this volcanic activity in Hawaii. Is that a warning sign to us? Is that something that could indicate that there might be some earthquake activity here? Does the volcanic activity in some way relate to earthquake activity?

Dr. HICKMAN. I think this is a question for me.

[Laughter.]

Mr. ROHRABACHER. Whoever can answer that.

Dr. HICKMAN. In the case of Hawaii, that is really not connected to the plate boundaries that cause the earthquakes. Hawaii is sitting on top of a hot spot coming up from the mantle. So it basically is being melted from below. Hawaii is the end of a chain of mountains that were formed by melting through the crust.

Mr. ROHRABACHER. Okay, so that is different.

Dr. HICKMAN. All by itself, it makes little earthquakes. We had a 6.9 earthquake associated with eruptions in Kilauea. That is pretty big, but that is not really part of the same problem we face here in California.

Mr. ROHRABACHER. One of the things, the last thing, and then I will make sure my colleagues get a chance to ask whatever questions you have.

I have been very concerned that we have nuclear energy facilities that, in an earthquake—I mean, look at what happened in Japan. They were told this is absolutely safe, there is no way you are going to have any problem with this, and then look at what happened in Japan.

Just very quickly, number one, let me just note that we can build the next generation of nuclear power—we are capable of that; we haven't done it yet—that I know would be safe. But currently, with these light-water reactors, which I think are inherently dangerous, are we safe now if there is an earthquake? Is that a part of this threat?

Just very quickly I will go down the line.

Dr. MCCABE. What do you mean is this part of the earthquake threat?

Mr. ROHRABACHER. Do you think that our current nuclear power plants can withstand a 7.5 earthquake and not leak radioactivity?

Dr. MCCABE. Well, the U.S. Nuclear Regulatory—I started out in the nuclear business, but I haven't been in that for quite a while. The U.S. Nuclear Regulatory Commission has each plant site do an in-depth seismology survey. So each individual plant is sited and is designed based on the risk that exists for that particular location.

Mr. ROHRABACHER. Okay. Let me ask you this: Where is San Onofre on the fault line here? Is it on the fault line? Is it down here? Okay. Well, it doesn't look that far away from a fault line to me.

Dr. MCCABE. If I were living in Southern California, I would have less concern about that because of all of the attention of all the engineers and all the regulators at the state and Federal level. I would have less concern about that than I would about, perhaps, other things that are out there. Risk is relative.

Mr. ROHRABACHER. It is. However, if that happens to go down, we are talking about millions of people being irradiated, as compared to some people who, maybe thousands of people losing their lives in unstructured buildings. Also, of course, I think that all the experts, as I say, just guaranteed the Japanese that there is just no possibility ever. What I think is very damaging and just outrageous is we are still trying to sell light-water reactors to different countries in the world, and they are inherently dangerous. We have the technology capabilities to build safer nuclear reactors, and we should.

But anyway, does anyone else have any comment on this?

Mr. POLAND. I just want to add to what Dr. McCabe said. I think that it is important not to compare buildings that were built without any consideration for seismic design, unreinforced masonry brick buildings, with a nuclear power plant, even if it was designed and constructed 30 years ago. It was given an extraordinary amount of consideration in design analysis by the best experts that we had because of the very threat that you are talking about.

One of the things that we saw in Japan, I believe, is that we had a black swan event. We had an event that nobody thought was going to happen, or at least the consensus of the community was that event was not going to happen. The wave wasn't going to be that high, we weren't going to experience that. So to me, I don't think it is proper—maybe I shouldn't say that. I think we have to recognize that that event was something completely out of the ordinary expectation.

But the main point I wanted to make was not to draw conclusions from very poorly built buildings and something that has been built deliberately in a very careful process.

Mr. ROHRABACHER. Well, they are two different threats, and I just have to say that I personally have been disturbed that we have not developed the next generation of nuclear power, which we know we can do, that would not leave us as vulnerable as the current system.

Mr. Takano?

Mr. TAKANO. Thank you, Mr. Chairman.

Mr. Poland, this $300 billion figure that you —

Mr. POLAND. Three hundred million.

Mr. TAKANO. Three hundred million.

Mr. POLAND. Million. You guys always say billion. We gulp to say million.

[Laughter.]

Mr. TAKANO. I was thinking $300 billion.

Mr. POLAND. Oh, no.

Mr. TAKANO. So, $300 million.

Mr. POLAND. We could fix all the buildings with that kind of money.

Mr. TAKANO. We could fix all the buildings. But that makes more sense, $300 million, which is not bricks and mortar but which is about research, which is about information. The picture I am getting from you is it would help us understand what buildings were built in a liquefaction area that would make little sense to invest a lot in retrofitting. But that information that the Federal Government would provide to the local planners and the building codes would say if you are going to build on areas of liquefaction going forward, you had better build to this standard or not build there, just discourage building there at all.

Mr. POLAND. Or accept the consequences, yes.

Mr. TAKANO. Well, it also, I assume, would bring the market into this, because insurance companies who underwrite earthquake insurance would be able to use this information also and price their policies accordingly.

Mr. POLAND. That is right.

Mr. TAKANO. So it would be government data that would also inform other kinds of market incentives to be able to drive this in the right direction.

Mr. Vernon, you have something to say about this?

Dr. VERNON. One other aspect of that $300 million per year, it also fully fills up the Advanced National Seismic System. So not only do you have the research component that you have talked about, it also gives us the seismic network monitoring capability that had been fully planned for. So that is another component of that $300 million a year.

Mr. TAKANO. It is not all the block by block analysis.

Mr. POLAND. No, that is one piece of it.

Mr. TAKANO. One piece of it.

Well, this has been a very fascinating hearing. I want to understand, is this research, the conclusions you have drawn about what people would do if they couldn't shelter in place, is that part of the social science that needs to be done? I understand that there is a social science aspect to responding to earthquake disasters.

Mr. ARBA. That certainly sounds like an opportunity for that. I think a lot of the focus on the social sciences, especially in the current environment with the focus on earthquake early warning, is how to best utilize that alert. But that is certainly an opportunity that could be pursued.

Mr. TAKANO. Go ahead, Mr. Poland.

Mr. POLAND. I would add one thing. The NIST Community Resilience Planning Guide, which is kind of the framework for this new generation of building codes and this new generation of thinking about how we want things to perform, starts by understanding what the social institutions are, and that is working with social scientists, and then prioritizes which of those social institution products and economic products are necessary at what time, and then how those are supported by the built environment. That is how the performance goals are developed.

That is something we have never done before, in my mind, is turn to the social science community and have them help us understand what people need, how they are going to respond, and what communities need in order to efficiently recover.

Mr. TAKANO. Mr. Arba, I understand that San Francisco and Los Angeles have undertaken major initiatives as described by Dr. McCabe, the ordinances they have passed, the commitment to look at what buildings need to be retrofitted, and there is a social justice element to how these ordinances were designed. I understand the California legislature is moving forward with some of its plans.

How is it that we can make sure that this reauthorization works in tandem and helps leverage what California is doing, and how can the Federal Government be of the best assistance to the State of California?

Mr. ARBA. Yes. I mean, certainly as these policy issues advance, as part of Cal OES and working with our partners, we are often looking to that research in order to make the decisions that we have to make on these separate considerations. So I would just say, consistent with what was said earlier about continuing to make sure that among all of the different research topics that we have that are covered in the NEHRP program, that a specific emphasis is called out for research as mentioned.

Dr. MCCABE. I will just add that we believe that the social science aspects, the policy aspects, are very, very important. We brought on social science expertise at NIST to help in this process because it all has to do with accepting the risk, making decisions about the risk, ultimately engaging in programs that will make things better. This is a very grassroots kind of thing, but you are talking about a community surviving and potentially flourishing. So it is not just the engineering, and that is a big part of this going forward.

Mr. TAKANO. So the seismic hazard maps—go ahead, Mr. Hickman.

Dr. HICKMAN. Yes, I was going to add—maybe that is where you are heading with your question. Getting the more kind of high-resolution pictures we need for seismic hazard in urban areas is something that people have done in Seattle and Los Angeles, but we need to do more of that. So urban seismic hazard mapping is one way to produce a very high-resolution picture, not quite block by block, but close, of how the ground is going to shake during an earthquake using realistic models for how the sediments focus the energy, where the faults are, how the faults might break.

So it is important to think about the science, too, because your liquefaction models depend upon the ground-shaking models, because it is ground shaking that causes liquefaction.

So when you think about this, think about the integrated package that involves the engineering, but also the earth science that feeds into that, and the social science that controls how people respond. I think that is the beauty of NEHRP, that we all work together on these problems. We are already working very closely with Cal OES on earthquake early warning, for example. So I would just like to see this sort of horizontal building of these kinds of models that depend on solid science, really good engineering, and then the social science to make sure people know what to do with the information they have.

Mr. TAKANO. Yes, I was going in that direction with the seismic maps, that that is going to be very useful for city planners, for insurance companies. More information will help. The market can also help guide us in the right direction as well.

But I think the public needs to understand the risks and where the liabilities are in a community, how are we going to address the low-income folks who are living in the riskiest areas that constitute our important workforce. We are a great economy, depending on which statistics the fifth or sixth largest economy in the world, and what happens to us if we become disabled? And the question is how disabled? And the perfect word again is resilience. How do we plan for resilience?

Thank you very much. I am going to yield back my time. This has been a fascinating hearing.

Mr. ROHRABACHER. Mr. McNerney?

Mr. MCNERNEY. Again, I thank the Chairman again. And again, I am going to follow up on Mr. Takano's question to Mr. Hickman.

You were talking about models or how we can model the kind of resolution to be helpful in planning. How advanced are the models that could be used to do that? Is that an area of research that the $800 million would go to?

Dr. HICKMAN. Absolutely, that is an area where more work is needed. We have very sophisticated computer models now. We are missing information, for example, on the structure of sedimentary basins beneath Seattle, beneath Los Angeles, beneath San Francisco. We know from Mexico City that sediments resonate with different earthquakes, and that has big implications for tall buildings and engineering.

So we need more information to characterize the geology beneath the big cities that face so much risk. We need more information on characterizing the faults that are along them. How are those faults likely to break based upon their past history? So that means doing more of what we call paleo-seismology, looking backward in time to see how faults broke over time. And we need to do more work on seismic wave propagation, how do the earthquake waves coming away from the fault change as they come up to the surface, and how are they modified by the soils. How does that lead to liquefaction? How do landslides occur?

There are a lot of unanswered questions. So I think the science, the drive, a lot of important hazard and risk reduction products here.

Mr. MCNERNEY. Would you say that is more empirical science or more computational theoretical?

Dr. HICKMAN. It is both. But we are computational. There are certainly super-computers churning away right now on these kinds of models, but we need more data to feed into those, and we also need more theoretical understanding.

Mr. MCNERNEY. Okay. Good.

I also want to hear a little bit more about the TAs and the ANSS. How do you say ANSS?

Dr. VERNON. It is the Advanced National Seismic System.

Mr. MCNERNEY. I mean, the TAs, are they flexible geographically? How does a TA work?

Dr. VERNON. It was a project that started under the National Science Foundation and is now pretty much finishing its end of life. It is completing its deployment in Alaska now. What we have left behind is this Central and Eastern U.S. network, which is now part of the ANSS —

Mr. MCNERNEY. But what is a TA?

Dr. VERNON. Transportable array. It is part of the EarthScope program under the National Science Foundation. It was an MREFC, Major Research Equipment Facility —

Mr. MCNERNEY. But what does it mean? Are there major sensors every few kilometers, or —

Dr. VERNON. Each station was deployed for about two years. There were 400 deployed at a time. You would pick one up on the back on the West Coast and move it more to the East, and they just kept rolling them forward. Each station was in place for about two years as we moved across the country.

Magically, right about the time in 2007 and 2008, we got into Oklahoma right when all the earthquakes started there, happening there.

Mr. MCNERNEY. How do they fit in with the ANSS?

Dr. VERNON. They inform the ANSS in the sense of where the seismicity is. It gives you a snapshot in time. It gives you more information about the structure, like Steve was talking about, talking about how do you actually get the amplitudes that you might expect from certain size earthquakes. So it gave us a data set that we can use to inform some of these models and studies that we are talking about, cross reference.

Mr. MCNERNEY. So is the ANSS also an array? What is it?

Dr. VERNON. No. The Advanced National Seismic System is a set of seismometers deployed permanently in the ground throughout the U.S. There are big components here in California. There is a Northern California Seismic Network, a Southern California Seismic Network. There is one in Washington. They are integrating them together to do these earthquake early warning systems. There is a big system in Alaska. There are ones in the Central U.S. around the New Madrid area.

Mr. MCNERNEY. Can the TA become part of the ANSS?

Dr. VERNON. It could have been if it were left in place, but we lost that opportunity. That is what I was trying to say. When we do these large-scale programs, we should be thinking about the longer-term implications, how we could leverage those investments to make more efficient use of the dollars that we do spend on science.

Mr. MCNERNEY. All right.

Dr. MCCABE. If I can add, ultimately if you are going to have an engineer design a building or a lifeline system, we need to know what the threat is, what the seismology is. Particularly in the eastern two-thirds of the country, that data provided by the TA system is invaluable. Rare events like the 2011 Mineral, Virginia earthquake revealed the importance of having instruments, even in places where you may not expect earthquakes to occur with regularity. But it is important for us to do our job as engineers.

Mr. MCNERNEY. Mr. Chairman, I yield back.

Mr. ROHRABACHER. Well, I want to thank our witnesses. I want to thank my two colleagues for joining us.

This has been, I would say, an enlightening hearing. It was fun, transmitting important information and doing so in a way that is interesting. Thank you, witnesses. Thank you very much for coming and sharing your expertise in the way you did.

Let me just say that I visited Pompeii with my family. Have you ever visited Pompeii? Pompeii was one of the most powerful cities in the world. People who have not been there should visit Pompeii to see what nature can do overnight. There you have this evidence that has been put down. People's bodies are covered with that soot and everything.

But what is most important is here you had this powerful city, and within a day it no longer really existed. We know that there are major challenges in nature. I mentioned asteroids or something like that, and we do need to make sure that we do understand that these challenges are there and what we can do about them. You have outlined today what we can do that would perhaps save lives in the long run and make sure that if there is a major earthquake, which there will be, in Southern California, that we survive that and that we minimize the suffering that will take place in one of these acts of nature.

So you have given us specific actions and specific policies that you said would help deal with that and help us minimize that type of suffering that would result from an earthquake. So let's hope that we can now—we understand the challenge. The biggest challenge is making sure we are responsible enough. If it is only $200 million, not even billions —

[Laughter.]

Mr. ROHRABACHER. When people come to us, it is always billions, right? Well, that is a very reasonable amount. But we have a trillion-dollar deficit we have to deal with. And I would hope that when we look at that issue of spending a trillion dollars more than we are taking in, that what you have talked about today, I believe a primary responsibility of government, especially the Federal Government, is to make sure that they protect the safety of the American people, both from foreign attack but also by natural disasters, what we are discussing today. So it is our responsibility. Thank you for giving us some insights that will be useful to us.

With that said, the record will remain open for two weeks for additional comments and written questions from members.

The hearing is now adjourned.

[Whereupon, at 3:58 p.m., the Committee was adjourned.]

Appendix I

Answers to Post-Hearing Questions

ANSWERS TO POST-HEARING QUESTIONS

Responses by Dr. Stephen Hickman

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

"Earthquake Mitigation: Reauthorizing the National Earthquake Hazards Reduction Program"

Dr. Stephen Hickman, Director, Earthquake Science Center, U.S. Geological Survey

Questions submitted by Representative Suzanne Bonamici, House Committee on Science, Space, and Technology

1. In Northwest Oregon, it is not a question of if, but when, an earthquake along the Cascadia Subduction Zone will hit our state. The U.S. Geological Survey, in collaboration with the University of Oregon, the University of Washington, Caltech, and UC Berkley, has developed ShakeAlert, an early earthquake warning system. The technology has been tested and is proven to work effectively.

   Can you provide an update on the timeline for implementation of a fully developed and tested national early earthquake warning system that can deliver messages to the general public? What plans does USGS have to educate the public about earthquake early warning alerts and how to respond to them?

   Answer: ShakeAlert has been focused on the West Coast of the United States (California, Oregon, Washington and Alaska). While this system could be available "border-to-border," at this time there is no definite timeline for the full implementation of this system. The President's Fiscal Year 2019 budget did not request continued funding for ShakeAlert. However, the USGS will work with stakeholders to determine the appropriate federal, state and local cost share associated with any future ShakeAlert developments.

   A plan for ShakeAlert communication, education and outreach (CEO) is in development, jointly with State and university partners. The group developing this plan includes broad representation, including from Oregon and Washington (see ShakeAlert.org for more information). This plan, when completed this summer, will detail the specific activities to be accomplished in the education realm and the parties responsible for undertaking them. We expect to provide about $870,000 this year for five of the most time-critical CEO projects identified in that plan.

   We note that the USGS must rely on external partners to undertake and accomplish much of the education needed to ensure that people and businesses take the most appropriate actions when they receive earthquake warnings. Our strategy is to coordinate public education and training related to ShakeAlert, not to assume responsibility for it, and our expectation is that the benefitting States will work to integrate ShakeAlert messaging within their existing earthquake education programs.

Appendix II

Additional Material for the Record

REPORT SUBMITTED BY REPRESENTATIVE JERRY MCNERNEY

CoreLogic

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May 31, 2018

Representative Lamar Smith
Chairman, House Committee on Science, Space, and Technology
2321 Rayburn House Office Building
Washington, DC 20515

Representative Eddie Bernice Johnson
Ranking Member, House Committee on Science, Space, and Technology
2321 Rayburn House Office Building
Washington, DC 20515

RE: *Earthquake Mitigation: Reauthorizing the National Earthquake Hazards Reduction Program*

Dear Chairman Smith and Ranking Member Johnson:

On behalf of CoreLogic (NYSE: CLGX) please accept the following statement and materials for the record regarding the Committee's recent field hearing on earthquake mitigation programs.

CoreLogic is a leading global property information, analytics and data-enabled solutions provider headquartered in Irvine, California. Our combined data from public, contributory and proprietary sources includes over 4.5 billion records spanning more than 50 years, providing detailed coverage of property, mortgages, hazard risk, consumer credit, tenancy, location, and related performance information. We serve diverse markets including real estate and mortgage finance, insurance, capital markets, and the public sector. Our vast data, powerful analytics, cutting-edge workflow technology, advisory and managed services help identify and manage growth opportunities, improve performance and manage risk.

CoreLogic's natural hazard and catastrophe solutions allow for insurers and enterprise risk managers to know property-level hazard risk across their portfolios. As the Committee recognizes, natural hazards including, but not limited to earthquakes, floods, wildfires, hurricane winds and tornadoes present threats to Americans and the economy every year. We believe that having access to the latest technology and most accurate hazard risk insights can help improve how communities prepare for and respond to these types of natural hazards. Using proprietary science, our predictive modelling has helped risk managers answer three critical questions: What could happen? What if it happened? And, what did happen? After the record-breaking catastrophes across the United States in 2017, CoreLogic spent time reflecting, analyzing and evaluating the severity of natural hazard events in an effort to inform and protect homeowners and businesses alike.

This letter contains two CoreLogic reports: our *2017 Natural Hazard Risk Summary & Analysis Report* contains a qualitative and quantitative evaluation of last year's natural hazard events; and our recently published report *Financial Implications of the HayWired Scenario*, a companion document to the USGS' analysis of a hypothetical massive earthquake along the Hayward fault. We hope these reports can serve as a resource to the Committee as it works with federal agencies, state governments, local communities, and private sector businesses to evaluate options and tools available to strengthen preparedness, response, and post-loss assessment capabilities across the United States.

Sincerely,

Stuart Pratt
Global Head, Public Policy and Industry Relations
CoreLogic

Title: *2017 Natural Hazard Risk Summary & Analysis Report*

Published By: CoreLogic

Date: January 25, 2018

https://www.corelogic.com/insights-download/natural-hazard-risk-summary-and-analysis.aspx

SPECIAL REPORT

Financial Implications of the HayWired Scenario

CoreLogic

HAYWIRED

Summary

The Hayward fault is one of the most dangerous faults in the United States. Running down the length of the San Francisco East Bay beneath densely populated and economically vital communities, the Hayward fault represents a clear and present danger of hosting a catastrophic earthquake. The last major earthquake along the Hayward fault was a magnitude (M) 6.8 on October 21, 1868[1] ; a repeat of such an event today would be devastating to the Bay Area.

In a series of reports, the United States Geological Survey (USGS) and a coalition of multi-disciplined collaborators describe a hypothetical magnitude 7.0 earthquake along the Hayward fault followed by 16 aftershocks of M5.0 or greater—collectively known as the HayWired earthquake scenario.[2]

This special report serves as an independent companion document to that scenario and highlights damage and insured losses from these events, including the effects of construction, property valuations, buy-rates (the fraction of properties insured for earthquake shaking is less than 100 percent), incremental damage resultant from aftershocks, and hours clauses[3] for insurance conditions—all of which will be explained in greater depth in this writeup.

CoreLogic® analyses of the main earthquake and subsequent aftershocks indicate that over 1.1 million homes are likely to suffer visible damage, with a smaller number expected to be functionally impaired. The total damage to private property for the entire sequence is estimated to be $170 billion, with only a small fraction of this insured.

"The HayWired scenario is not a prediction of events to come, but it is a realistic portrayal of a series of earthquakes that could credibly occur along the Hayward fault," said Tom Larsen, principal, industry solutions for CoreLogic. "Our analysis evaluates the interaction between the physical aftermath of the events, with earthquakes and aftershocks occurring over time, and the financial world of insurance policies. Assessing that interaction can help determine how such a catastrophic event, in conjunction with the low penetration rate of residential and commercial earthquake insurance, can have significant and long-lasting damage on the people and economy of the region."

Accounting for the effects of aftershocks and the manner in which these aftershocks can be expected to impact insurance payments to homeowners produces an estimate of the amounts recovered from insurance at $30 billion, approximately 17.6 percent of the total damage. This leaves 82.4 percent (or $140 billion) of the losses unable to be recouped. The difference between the estimated property damage and the amount recovered by insurance is driven largely by the estimated property damage and the amount recovered by insurance is driven largely by the lack of insurance for most properties in California and, to a lesser degree, the effect of insurance deductibles and limits.

"The HayWired scenario is not a prediction of events to come, but it is a realistic portrayal of a series of earthquakes that could credibly occur along the Hayward fault. Our analysis evaluates the interaction between the physical aftermath of the events, with earthquakes and aftershocks occurring over time, and the financial world of insurance policies. Assessing that interaction can help determine how such a catastrophic event, in conjunction with the low penetration rate of residential earthquake insurance, can have significant and long-lasting damage on the people and economy of the region."

TOM LARSEN,
PRINCIPAL, INDUSTRY SOLUTIONS FOR CORELOGIC

Planning is a Necessary Pre-Cursor to Rapid Recovery

Insurance has historically played an important role in the recovery of communities and economies following natural catastrophes. In 2010-2011, a series of earthquakes in and around Christchurch, New Zealand, caused significant stress to the financial recovery system. The added complexity of the sequence of earthquakes in the HayWired scenario allows us to explore and quantify consequences of the cascading earthquakes.

The earthquakes addressed in this report are documented more completely in the USGS report.[2] The epicenters of the earthquakes are mapped on page four, highlighting the geographic concentration of the main shock and aftershocks in the San Francisco Bay Area. The goal of this exercise is to investigate the financial impacts resulting from the earthquake occurrences and the expected performance of the estimated insurance policies in place to assist recovery and reconstruction.

Earthquakes are inevitable in this region. There are millions of buildings in the Haywired study region, built to varying strength standards and at varying levels of deterioration due to age or deferred maintenance. Despite modern building codes which produce stronger construction, the diversity of buildings in the region make earthquake damage inescapable. A key component of resiliency is to ensure that adequate capital will be available to assist in the recovery from earthquake-induced damage. Effective responses and recovery plans can be implemented only in the presence of reliable estimates of the damage and insurance recoveries following the events.

The HayWired scenario was created by the USGS and a coalition of multi-disciplined contributors as a credible depiction of a series of catastrophic earthquakes with the intention to deeply explore the implications of such set of events.

What might the impacts and consequences be if another earthquake like the 1868 event were to happen today [along] the Hayward fault? The HayWired scenario examines one such hypothetical earthquake—a M7.0 earthquake on April 18, 2018, at 4:18 p.m. [and] asks the following questions:

- What is a scientifically [reasonable-size] earthquake that people can expect and prepare for along the Hayward fault?
- What could happen as a result of the HayWired scenario earthquake and its cascading effects (or in other future damaging events in the San Francisco Bay region), and what can we do about it?
- What can San Francisco Bay region residents, communities, and businesses do to prepare for an event like that in the HayWired scenario?
- How can we learn more about the effects of a disaster like that modeled in the HayWired scenario and take action and support actions by others to prepare for such an event?

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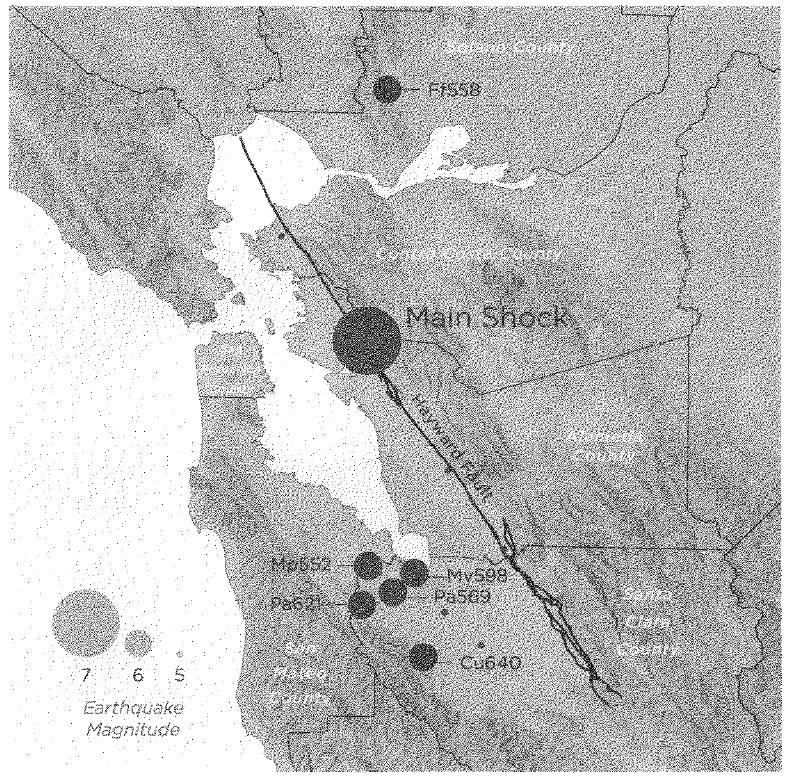
Figure 1: Locations and magnitudes of the HayWired shocks



Quantifying Earthquake Risk

Important Terms and Facets

In the moments during and immediately after an earthquake, many types of damage can be observed. The practice of insurance in the U.S. is to offer specific peril endorsements, so the damage must be estimated for each of these specific sub-perils of an earthquake. In all aspects of loss estimates, damage is the estimate of monetary cost to repair the property to the condition it was in prior to the occurrence of the earthquake.

Direct earthquake ground shaking damage is the most common damaging impact of earthquakes. The susceptibility of property to direct ground shaking damage is a complex function of ground motion duration, ground motion peak intensity, and construction characteristics such as materials, building codes, and occupancy. Earthquake ground shaking damage is indemnified by a specific earthquake ground shaking policy or endorsement.

Earthquake sprinkler leakage is caused by leaking building fire sprinkler pipes. Water pipes are susceptible to leakage after an earthquake due to the interaction between the earthquake induced motion of the building and the sprinkler systems. Recent California legislation has mandated the inclusion and retrofitting of fire sprinklers into many structures that had previously been lacking these important systems. However, the presence of fire sprinklers also produces an increased risk for leakage of the sprinkler pipes during and after significant earthquakes and the ensuing water damage that is produced.[4] Earthquake sprinkler leakage is presumed to be covered by a homeowner's policy in the residential analysis below. In some commercial properties' insurance policies, sprinkler leakage is an optional insurance coverage and results in the model are pro-rated to account for partial coverage.

Fire-following earthquake is the term used to describe the phenomena of urban fire conflagration following an earthquake. Driven by the potential for earthquake induced ignition sources, fueled by potential broken gas lines, with control hampered by possible damage to firefighting capabilities, fires are a part of many historic earthquakes. Fire-following earthquake losses are tabulated separately from earthquake ground shaking losses because fire-following earthquake is covered under the standard fire policy for the preponderance of fire insurance policies in California.

Reconstruction cost is used as an input to the earthquake risk model to estimate damages. The reconstruction cost differs from the cost of construction in many ways. Repairing a property is far more time consuming and labor-intensive than new construction because it includes debris removal, labor rate surges, and low availability. Post-catastrophe demand surge spikes as the urgent need for repairs can overwhelm available labor and materials resources. The valuations used in this study are summarized by county in Appendix Table 1.

Buy-rate refers to the portion of the populace that purchases insurance. Sometimes referred to as purchase rate or insurance penetration rate.

For this report, the term *direct damage* refers to estimates of the financial damage to all properties in the region. The term *insurance loss* refers to the amount of money private insurance companies are expected to pay to their policy holders to restore insured properties. In practice, residential earthquake insurance policies have deductibles typically varying from 15 percent to 25 percent of the reconstruction cost of the structure. *Insurance loss* refers only to the amount paid by the insurer above the deductible. The insured peril of fire-following earthquake is generally covered by the homeowners' policy.[5] Fire insurance deductibles are typically smaller than earthquake deductibles. Sprinkler leakage is usually covered by a homeowners' policy as a pipe burst. For this analysis, we presumed that sprinkler leakage was covered by the fire insurance policy.

The HayWired earthquake scenario postulates a series of earthquakes that affect the same set of buildings. In the time sequence imposed by this scenario, it is very unlikely that properties will be repaired in the interval between earthquakes. The concept of *incremental damage*—that in which properties will be subsequently damaged by aftershocks—was considered in this report, and to the best extent possible, incremental damage was estimated based upon the damage state at the time of the event and the severity of ground motions.

A property insurance policy is a legal contract between the property owner and the insurer. The wording of the contract must be considered in the evaluation of insurance loss.

Earthquake insurance contracts typically provide insurance coverage on an occurrence basis, with the contractual definition of an occurrence considering a specified hours clause. An aftershock that occurs outside of the hours clause timeframe may be considered a new occurrence for which a homeowner must satisfy an additional deductible before the insurance policy will provide additional payment to the homeowner. With California earthquake policies often having significant deductibles, earthquakes that outlast the timeframe of the hours clause can result in a significant diminution in the benefits of the insurance coverage to the insured.

A survey of earthquake policies purchased in California indicated that the most common contractual definition of an earthquake occurrence for a residential earthquake policy is 360 hours. For the analysis below the damage from all earthquakes and aftershocks with a 360-hour period were accumulated and only one earthquake insurance deductible was applied to the cumulative damage within this period of time. A 168-hour time clause was considered for commercial damage. From an insurance policy perspective, the incorporation of the hours clause "converted" the 17 earthquakes in the HayWired scenario to five residential earthquake insurance events and eight commercial earthquake insurance events.

The analyses in this report were completed using CoreLogic data and analytics. The CoreLogic Insurance Exposure Database (IED) was used to model the location, characteristics, and valuation distribution of properties in the San Francisco Bay Area. The U.S. Earthquake Model from CoreLogic, a probabilistic and scenario catastrophe loss model, was used in conjunction with the ground motion maps provided by the USGS to estimate direct damage and insured losses for all scenarios. This model computes direct damage and insured loss estimates for single earthquake ruptures, and secondary models were developed to estimate the incremental damage from the earthquakes and to estimate the impacts of a single deductible applying to multiple earthquakes.

The HayWired earthquake scenario postulates a series of earthquakes that affect the same set of buildings. In the time sequence imposed by this scenario, it is very unlikely that properties will be repaired in the interval between earthquakes. The concept of incremental damage—that in which properties will be subsequently damaged by aftershocks—was considered in this report, and to the best extent possible, incremental damage was estimated based upon the damage state at the time of the event and the severity of ground motions.

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The Big One

The main shock (M7.0 near Oakland, California,) is the most severe damage and loss event. The extent of the damage encompasses most of the San Francisco Bay Area. CoreLogic estimates almost 1 million homes damaged from this event. The monetary estimates of damage from this event are to the right.

The main shock produces damage broadly throughout the San Francisco Bay area, but the damage is concentrated in Alameda County (Appendix Table 2). Contra Costa and Santa Clara counties are also expected to see significant damages from a large earthquake along the Hayward fault.

These estimates display only the mean damage. The uncertainty in risk modeling cannot be ignored: time of day, day of the week, weather, and other unforeseeable effects cannot be predicted and thus all loss estimates include a range of uncertainty. The geographic distribution of losses is consistent with the distribution of damage (Appendix Table 3).

Effects of Aftershocks

The incremental effects of the aftershocks are tabulated, first as a listing by each individual aftershock, second as a listing of cumulative aftershocks, and finally added to "The Big One" to provide the combined impact.

The HayWired scenario includes 16 specific aftershock earthquake occurrences distributed in time throughout the San Francisco Bay Area. The Cu640 and the Pa621 aftershocks are the most damaging (Appendix Table 4), consistent with their being the highest magnitude aftershocks.

Aftershock damages are concentrated in Santa Clara county (Appendix Table 5), consistent with the Cu640 and Pa621 aftershocks located in Santa Clara County.

Table 1: Direct Damage from Main Shock

	Total	Residential	Commercial
Ground-Shaking	$140	$60	$80
Fire Following	$2	$1	$1
Sprinkler Leakage	$2	$1	$1

Source: CoreLogic December 2017. Dollars reported in billions.

Table 2: Insured Loss from Main Shock

	Total	Residential	Commercial
Ground-Shaking	$26.5	$5.3	$15.9
Fire Following	$2	$1	$1
Sprinkler Leakage	$2	$1	$1

Source: CoreLogic December 2017. Dollars reported in billions.

Table 3: Cumulative Direct Damage from aftershocks

(automobile damage included in residential and commercial)

	Total	Residential	Commercial
Ground-Shaking	$24	$9	$15
Fire Following	$0.05	$0.02	$0.02
Sprinkler Leakage	$2	$1	$1

Source: CoreLogic December 2017. Dollars reported in billions.

Table 4: Cumulative Insured Loss from aftershocks

	Total	Residential	Commercial
Ground-Shaking	$26.5	$5.3	$15.9
Fire Following	$2	$1	$1
Sprinkler Leakage	$2	$1	$1

Source: CoreLogic December 2017. Dollars reported in billions.

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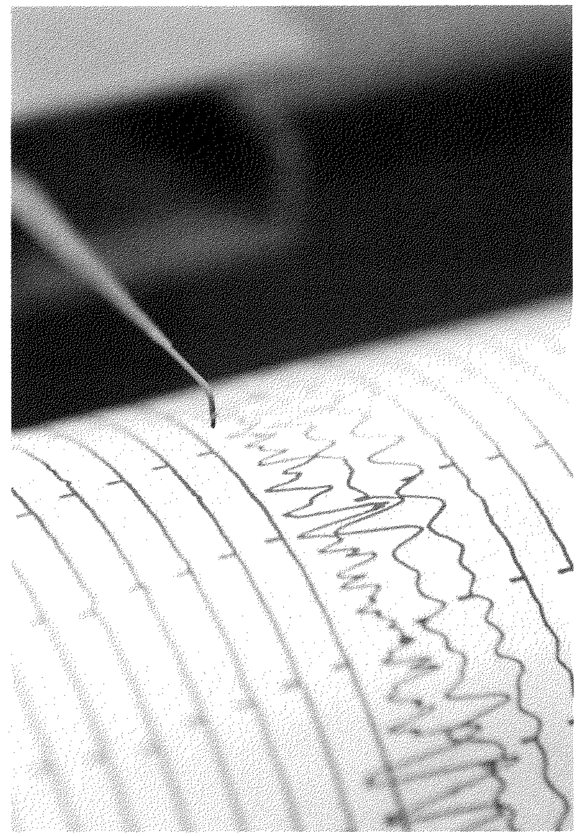
Sensitivity Analysis



Post-Earthquake Phenomena

There are many phenomena following an earthquake that can have a significant effect on the financial impact of the event (or events). Key sensitivities contributing to this fluctuation in estimated cost include:

- Demand surge, or post-catastrophe inflation
- Damage to key infrastructure and impacts upon resilience
- Weather and the impacts upon fire-following

Demand surge characterizes the increase in labor and materials costs following a catastrophe compared to the 'normal' labor and materials costs prior to the event. Following a catastrophe, the urgent demand for building materials and skilled labor can easily exceed the local pool of resources available. Less-efficient means of housing imported labor and bringing in supplies is a major component of demand surge. The 1996 earthquake insurance rate filing for the California Earthquake Authority (CEA) accepted an estimated 20 percent demand surge in the Northridge Earthquake (1994). The estimates in this report include demand surge factors that vary through the region depending upon local and regional demands for resources.

Damage to infrastructure is not explicitly accounted for in these estimates. Damaged infrastructure occurs in the form of damaged bridges, roads, and highways as well as critical utilities such as electrical, water, gas, and telecommunications including internet connectivity. The estimates in this report presume that infrastructure will be functional within days or weeks of the event. Permanently damaged infrastructure could greatly increase loss estimates by imposing additional costs upon those performing repairs.

Weather, or specifically wind speeds, can greatly influence the likelihood of an urban conflagration. Wind speeds are a critical factor in the extent of post-earthquake fire-following losses. Immediately after an earthquake, firefighters will be focusing on life safety for people in collapsed buildings. Heavy winds occurring at the same time will enable fires to quickly grow before resources are available to fight them, increasing the potential of large fires.

The scenario factors addressed in the development of the marginal damage estimate include identifying which shock caused the most violent ground motions at the location, the damage from prior events, and the interval since the last damage shock. The relationship between marginal damage and the modeled damage varies by event. The Mountain View, Cupertino, Sunnyvale, and Santa Clara sequence of aftershocks (Mv598, Cu640, Sv535, and Sc509 as defined by the HayWired scenario[2]) highlights this variability - these particular aftershocks come six months after the main shock, allowing time for repairs, and ground motions in this area are generally more severe from the localized aftershocks than they were for the more distant main (but larger magnitude) shock.

Loss Estimation

Estimating the insured loss to properties from an earthquake requires the identification of the properties which are insured and the estimation of their insured coverages (deductibles, limits, inclusions, and exclusions). CoreLogic uses public information from rate filings and summary reports from the California Department of Insurance (DOI) to verify and complete this data. The data from personal lines' insurance is more certain due to the completeness of regulatory reporting in admitted lines and the relative homogeneity of this line of business.

The data from commercial lines of insurance contains significantly more uncertainty, and there are many factors that can influence the likelihood of a business owner or operator to purchase earthquake insurance coverage. In addition, insurers have demonstrated tremendous flexibility in varying insurance terms such as deductibles. As noted above, insurance loss is calculated using the insurance hours clause definition of an earthquake occurrence and not the physical occurrence of an earthquake rupture. Insurance payouts are an important component of regional resilience.

Earthquake Scenario Descriptions

Analysis was done using the ground-motion footprints available from the USGS for the sequence of events. The events are listed to the right and are delineated as individual occurrences and will be referenced by a unique descriptor name, as defined by the HayWired scenario (e.g., "Uc523" references the magnitude 5.23 event in Union City on 4/18/2018).[2]

Name	Date/Time in PDT	Lat	Lon	Location	Depth (km)	Mag
main	4/18/18 4:18 AM	37.8	-122.18	Oakland	8.00	7.00
Uc523	4/18/18 4:49 PM	37.6	-122.02	Union City	2.65	5.23
Sp504	4/19/18 4:16 AM	37.96	-122.35	San Pablo	2.65	5.04
Ff558	4/29/18 11:13 PM	38.19	-122.15	Fairfield	11.05	5.58
Fr510	5/2/18 8:44 PM	37.48	-121.91	Fremont	7.15	5.10
Ok542	5/20/18 8:37 AM	38.19	-122.15	Oakland	8.45	5.42
Pa621	5/28/18 4:47 AM	37.39	-122.18	Palo Alto	18.97	6.21
Mp552	5/28/18 8:11 AM	37.45	-122.17	Menlo Park	7.26	5.52
At511	5/28/18 6:22 PM	37.46	-122.18	Atherton	7.91	5.11
Pa569	5/28/18 11:53 PM	37.41	-122.12	Palo Alto	8.36	5.69
Pa522	6/23/18 8:27 PM	37.44	-122.15	Palo Alto	2.85	5.22
Pa526	7/1/18 11:19 AM	37.44	-122.16	Palo Alto	8.69	5.26
Mv598	9/30/18 8:16 PM	37.44	-122.08	Mountain View	11.29	5.98
Cu640	10/1/18 12:33 AM	37.31	-122.06	Cupertino	15.45	6.40
Sc535	10/1/18 2:24 AM	37.38	-122.02	Sunnyvale	18.89	5.35
Sc509	10/1/18 6:10 AM	37.33	-121.95	Santa Clara	7.00	5.09
Pa501	8/22/19 10:45 PM	37.41	-122.12	Palo Alto	11.98	5.01

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Fire-Following Earthquake

Earthquakes are typically coupled with fire ignitions because of the interaction between the built environment and shaking associated with earthquakes. The basic elements of a catastrophic fire analysis are ignitions, fuel, and air. Reviews of past earthquakes show that fire ignitions are a function of ground motion intensity and housing density.

The predominant fuel for urban and suburban catastrophic fires is the building materials used in construction. In the San Francisco Bay area, the predominant residential construction is wood, although the prevalence for wood residential construction changes within communities. Commercial construction tends to be constructed from fire-resistant materials, and larger commercial facilities have separations that inhibit fire spread.

Air is a critical component in the estimation of the potential for catastrophic conflagration following an earthquake. A fire that can quickly spread to burn thousands of buildings requires the presence of extreme winds. The 2017 wildfire events in the Sonoma and Ventura counties were concurrent with extreme winds reported to exceed 40 miles per hour[6]; winds of this severity can generate a fire spread rate that easily overwhelms a fire response service that is distracted with other life safety priorities. Diablo winds, where high speed and warm winds flow from the Diablo Valley to the east across the Hayward fault zone have the capability to greatly increase fire risk, and in conjunction with an earthquake result in serious conflagration. These conditions typically peak in the fall and spring.

There are many uncertainties involved with earthquake risk modeling. The uncertainties range from the neighborhood level (imperfect information of the properties) to the aggregate level (time of day and day of the week can influence the effects of earthquakes, but models that account for these factors were not used in this study). This study focuses on the expected value of the damage and loss given the knowns and unknowns. For the sub-perils of earthquake shaking and sprinkler leakage, the average outcome is useful because the impacts of these uncertainties are generally a small shift in the outcome.

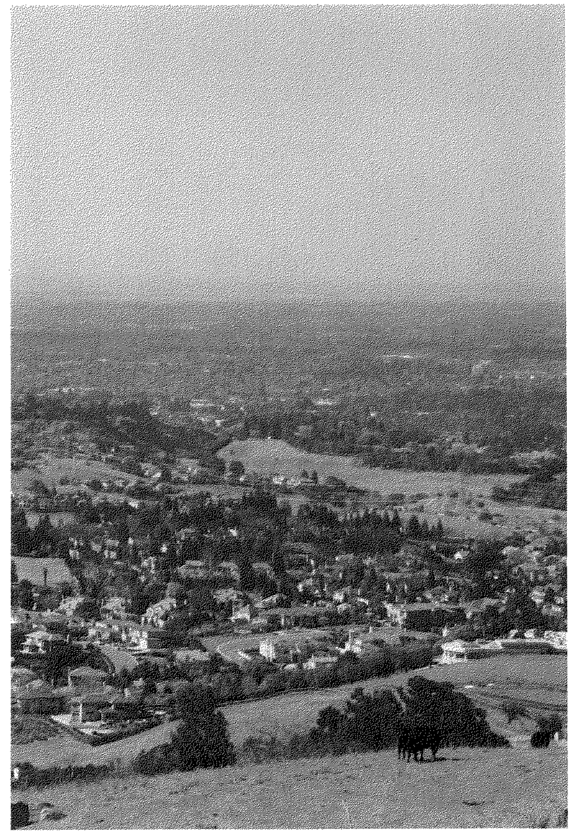
The sub-peril of fire-following earthquake behaves differently than the shaking and sprinkler leakage sub-perils. The rare occurrence of very large fire losses following earthquakes (the 1906 San Francisco earthquake[7] had very large fires as did the 1995 Hyogoken-Nanbu (Kobe) earthquake[8] where more than 6000 homes were destroyed) supports the argument that fire-following earthquake is a "tipping-point" risk where, if conditions are adverse, the loss potential is quite large. To maintain consistency with the overall study, the average fire-following earthquake loss estimate is used in this study.

Sprinkler Leakage

A significant potential impact of earthquake ground motion on buildings equipped with automatic fire sprinkler systems is that such systems can be damaged by the earthquake, resulting in sprinkler leakage. The severity of the resultant damage varies with occupancy and the assets that are wetted by the sprinklers. Detailed reviews of past events indicate that sprinklers are likely to cause damage in future events, even in buildings which suffer only slight structural damage. Improvement of fire protection standards for building construction in the preceding decades has led to the presence of fire sprinklers in new construction throughout the area.

In 2011 the State of California required that sprinklers be installed in all new construction of one- to two-unit homes although many municipal ordinances imposed this requirement earlier. Multi-unit residential and commercial properties have had sprinkler requirements for much longer and a much higher portion of these types of occupancies have either partial or full sprinklered floor areas. These systems mitigate fire risk but do have the potential side effect of being the source of water damage following significant earthquakes.

Report Conclusion



Although California has a history of large, damaging earthquakes and is the most seismically active region of the contiguous U.S., the damage experienced in California earthquakes to date has yet to eclipse $40 billion. That peak occurred in 1994 as a result of the catastrophic Northridge Earthquake.[9] In contrast, the projected $170 billion of the HayWired scenario would account for 20 percent of the 2016 regional Gross Domestic Product (GDP).[10] This is comparable to the devastating Christchurch earthquake sequence in 2010-2011, which had resultant damages representing ~25.3 percent of the region's GDP.[11,12]

Insurance payments to property owners are estimated to be approximately $30 billion, less than 20 percent of the overall damage. This is primarily due to the very low purchase rate of insurance.[13] The $140 billion financing shortfall ($170 billion less $30 billion in insurance) presents a real risk to effective regional recovery. Of special concern is the potential for systemic impacts triggered by the lack of insurance. A great portion of the property damaged by the earthquake serves as collateral for property mortgages. Delinquency rates are expected to increase after a large earthquake, as has been observed in Superstorm Sandy (2011) and Hurricane Katrina (2005).[14] The severity of uninsured damage in this earthquake scenario loss estimate is far greater than the damage estimates for Sandy and Katrina and the resilience of this market is uncertain for this level of severity. The disruption potential from a much larger event is very sensitive to the speed of recovery of housing and commerce.

The cumulative effect of aftershocks increases the losses by about 10 percent for the HayWired scenario. The losses from the modeled aftershocks are strongly influenced by their location relative to the main shock as well as the built environment. In this scenario, the event Cu640 was the most expensive aftershock for two reasons – the Cu640 aftershock was the largest magnitude aftershock, and being distant from the primary earthquake meant that it impacted properties with typically very low levels of existing damage.

The inclusion of aftershocks into the risk evaluation better aligns the planning scenario with the potential for earthquake occurrences in California and produces a more pragmatic planning scenario than a scenario that does not account for such aftershocks. It must be cautioned that it is impossible to predict the location and magnitude of earthquake aftershocks and the damage and loss increase of 10 percent is appropriate only for the scenario evaluated here.

The effect of the insurance policy hours clause benefits policy holders in this analysis. Earthquake deductibles are often 5 to 25 percent of the reconstruction cost of the property and earthquake damage rarely exceeds this. In this exercise, there were many properties where the modeled incremental damage from an aftershock was less than the earthquake deductible, but due to prior damage, the additional damage was recoverable under insurance.

It's not a matter of if but when a catastrophic earthquake will strike California. Citizens, homeowners, and businesses all must prepare for the devastating impact that may result. Earthquake insurance offers a means to help aid in the financial recovery of a devastating event.

The damage from earthquakes presents a real risk to California, and our ability to influence the effects of earthquakes range from building stronger buildings to developing rapid response and rebuilding plans. Eight years later and Christchurch, New Zealand, is still in the process of recovery. With a better understanding of a practical planning scenario for the effects of an earthquake, we can begin to rethink how we respond to these disasters and thus improve our ability to recover.

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About CoreLogic

CoreLogic (NYSE: CLGX) is a leading global property information, analytics and data-enabled solutions provider. The company's combined data from public, contributory and proprietary sources includes over 4.5 billion records spanning more than 50 years and providing detailed coverage of property, mortgages and other encumbrances, consumer credit, tenancy, location, hazard risk and related performance information. The markets CoreLogic serves include real estate and mortgage finance, insurance, capital markets, and the public sector. CoreLogic delivers value to clients through unique data, analytics, workflow technology, advisory and managed services. Clients rely on CoreLogic to help identify and manage growth opportunities, improve performance and mitigate risk. Headquartered in Irvine, Calif., CoreLogic operates in North America, Western Europe and Asia Pacific. For more information, please visit www.corelogic.com.

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Appendix

Appendix Table 1: CoreLogic Reconstruction valuations used in study ($ million)

Values represent the reconstruction cost of buildings plus building contents, automobiles. Insured loss estimation includes additional living expense and time element coverages.

Reconstruction Values used in Study ($ million)

Alameda	$264,562
Contra Costa	$230,362
Mari	$45,844
Napa	$23,677
San Francisco	$198,897
San Mateo	$125,023
Santa Clara	$306,891
Solano	$74,767
Sonoma	$87,957
Surrounding Counties	$660,938
Totals	$2,018,916

Source: (CoreLogic 2018); 2016 dollars

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Appendix Table 2: CoreLogic estimates of property damage (shake only) for the M 7.0 HayWired scenario mainshock (excluding fire and sprinkler damage) ($ million)

	Commercial ($ million)	Residential ($ million)	Automobile ($ million)	Total ($ million)	v Total Damage
Alameda	$28,065	$32,235	$208	$60,509	43%
Contra Costa	$13,139	$7,620	$50	$20,809	15%
Marin	$1,150	$806	$6	$1,962	1%
Napa	$751	$343	$5	$1,099	1%
San Francisco	$7,902	$1,975	$18	$9,895	7%
San Mateo	$4,407	$3,209	$25	$7,641	5%
Santa Clara	$14,241	$10,471	$83	$24,795	18%
Solano	$1,297	$681	$8	$1,986	1%
Sonoma	$3,601	$1,890	$21	$5,512	4%
Surrounding Counties	$4,269	$1,123	$26	$5,418	4%
Totals	$78,821	$60,352	$451	$139,625	100%
% Total	56.5%	43.2%	0.3%	100%	

Source: (CoreLogic 2018); 2016 dollars

Appendix Table 3: CoreLogic estimates of insured loss for the M 7.0 HayWired scenario mainshock (excluding fire and sprinkler damage) ($ million)

	Commercial ($ million)	Residential ($ million)	Automobile ($ million)	Total ($ million)	% of the Insure Loss Total
Alameda	$8,994	$3,670	$36	$12,700	60%
Contra Costa	$1,727	$523	$0.40	$2,251	11%
Marin	$70	$95	~0	$165	1%
Napa	$57	$6	~0	$63	0%
San Francisco	$860	$97	~0	$956	5%
San Mateo	$692	$269	$0.20	$962	5%
Santa Clara	$2,997	$524	$0.40	$3,522	17%
Solano	$131	$7	~0	$138	1%
Sonoma	$242	$81	$0.10	$324	2%
Surrounding Counties	$73	$12	~0	$86	0%
Totals	$15,844	$5,286	$37	$21,167	100%

Source: (CoreLogic 2018); 2016 dollars

Appendix Table 4: CoreLogic estimates of incremental damage for each HayWired aftershock (including fire and sprinkler damage) ($ million)

Name	Total Damage adjusted for prior damage ($ million)
Uc523	$180
Sp504	$240
Ff558	$90
Fr510	$197
Ok542	$727
Pa621	$4,940
Mp552	$515
At511	$488
Pa569	$1,163
Pa522	$893
Pa526	$676
Mv598	$2,780
Cu640	$8,911
Sv535	$1,223
Sc509	$620
Pa501	$358

Source: (CoreLogic 2018); 2016 dollars

Appendix Table 5: CoreLogic estimates of incremental damage for all HayWired aftershocks (including fire and sprinkler damage) ($ million)

	Commercial ($ million)	Residential ($ million)	Automobile ($ million)	Total ($ million)	% of the Insure Loss Total
Alameda	$1,786	$710	$18	$2,514	11%
Contra Costa	$446	$89	$3	$538	2%
Marin	$19	$2	$0	$22	0%
Napa	$5	$1	$0	$7	0%
San Francisco	$342	$21	$2	$364	2%
San Mateo	$2,210	$1,187	$19	$3,416	14%
Santa Clara	$9,722	$6,702	$88	$16,513	70%
Solano	$48	$10	$1	$59	0%
Sonoma	$3	$0	$0	$3	0%
Surrounding Counties	$208	$40	$3	$250	1%
Totals	$14,789	$8,762	$134	$23,685	
% Total	62.44%	36.99%	0.57%		

Source: (CoreLogic 2018); 2016 dollars

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